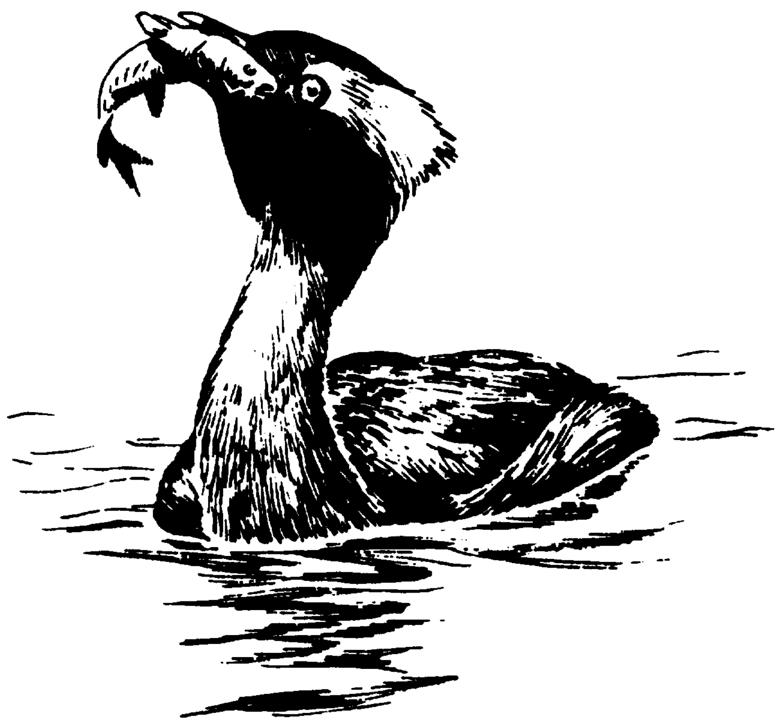
ECOREGION TARGETING FOR IMPAIRED LAKES IN SOUTH DAKOTA



South Dakota Watershed Protection Program
Division of Financial and Technical Assistance
South Dakota Department of Environment and Natural Resources
Nettie H. Myers, Secretary

May, 2000

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May, 2000

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1.0 Ecoregion Targeting

1.1 Introduction

South Dakota is a rural, agricultural state with a surface area of 77,047 square miles. Rolling plains are the main feature of this prairie state. The most visible of South Dakota's geographic features are the Missouri River which divides the state into 'east-river' and 'west-river' areas, and the Black Hills - an isolated area of granitic uplift in the far west. The maximum elevation of the state is 2,210 meters (7,242 feet), at Harney Peak in the Black Hills. The lowest elevation, 294 m (965 feet), is near Big Stone City in the bed of Big Stone Lake.

Past surveys by the South Dakota Department of Game, Fish and Parks have indicated there are approximately 800 publicly owned lakes in the state including 260 natural lakes formed primarily by glacial action. Most of the latter are concentrated in the northeast corner of the state within a glaciated plateau known as the Prairie Coteau.

The unglaciated west-river mixed grass prairie of South Dakota has few natural lakes but has a number of man-made lakes, numerous small farm ponds, three large reservoirs, and three Missouri River mainstem reservoirs. The most of the lakes within the Black Hills are artificial impoundments with the exception of a few small sinkholes.

The particular geology of an area exerts considerable influence on both the surface and ground water quality. Rothrock (1943) and Flint (1955) recognized 12 major physical regions within state boundaries. As a result of this geologic diversity, the water quality of the state is highly variable. The water quality of eastern South Dakota (Prairie Coteau) is indicative of the types of glacial drift deposited and the Dakota Sandstone aquifer (Nickum, 1969).

South Dakota has a sub-humid to semiarid climate subject to periods of drought at roughly 20-year intervals. Due to the shallow nature of the lake basins formed by glaciers in this region, average water depth of eastern state lakes is less than eight feet. During a prolonged drought many may dry up completely while others are reduced to very low water levels with attendant high salt concentration.

For this reason, most of the prairie lakes of eastern South Dakota can be classified as semi-permanent. They respond quickly to changes in annual rainfall and the underlying water table with fluctuations in lake water levels and water quality. The majority of state lakes tend to be turbid and well supplied with dissolved salts, nutrients, and organic matter mostly by runoff from agricultural and domestic sources. The shallowness of the lakes together with the mixing action exerted by strong summer winds prevent the establishment of enduring thermal stratification in all but a few cases.

Intensive agricultural practices have contributed greatly to the cultural process of lake eutrophication via soil loss and sedimentation. Fortunately, much of the cultural process can be prevented or impeded by the planned and timely application of the lake preservation and restoration measures adopted by the South Dakota Water Resources Assistance Program (WRAP).

Due to differences in geography, there are vast differences in the state's ecoregions. There are 8 Level III ecoregions in South Dakota (Figure 1.1). The Black Hills are in the ***Middle Rockies*** ecoregion. The ***Northwestern Great Plains*** ecoregion covers most of the South Dakota prairies west of the Missouri River. Also found in western South Dakota is the ***Western High Plains*** ecoregion along Pine Ridge in southwestern South Dakota. There is a small area of the ***Nebraska Sandhills*** ecoregion that encroaches on the southern border of South Dakota in Shannon, Bennett, and Todd counties. The ***Northwestern Glaciated Plain*** ecoregion covers the Missouri River plateau east of the Missouri River. There is a small area of this ecoregion reaching into the west river area near the Nebraska border. The ***Northern Glaciated Plains*** ecoregion covers the majority of eastern South Dakota from the James River valley to the eastern border. Only two smaller Level III ecoregion areas are found in the rest of the state. The extreme northeastern corner of the state is touched by the ***Lake Agassiz Plain***, which extends north into the Red River Valley. Also, patches of the ***Western Corn Belt Plains*** ecoregion encroach into South Dakota from the borders of southwest Minnesota and northwest Iowa.

South Dakota Level III Ecoregions

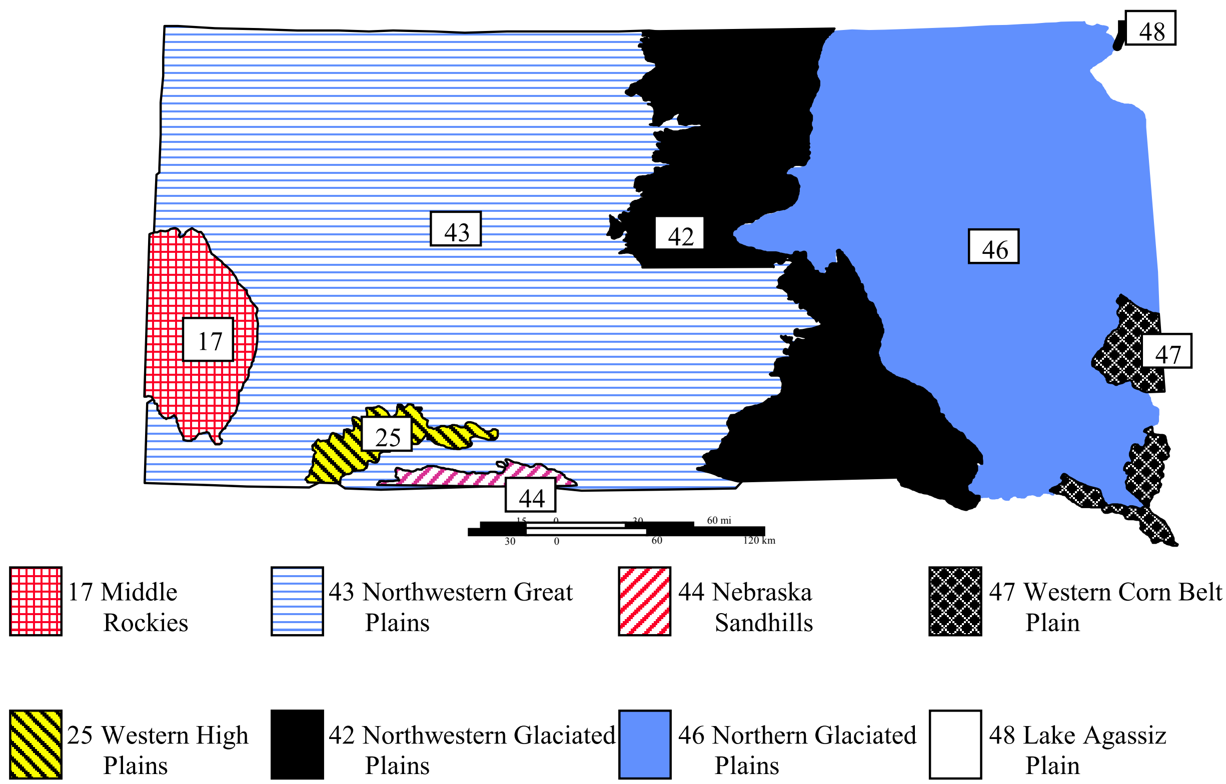

Figure 1.1. South Dakota Level III Ecoregions

By definition, ecoregions are different in geology, climate, and biota. Lakes within these ecoregions are also different from lakes in other ecoregions. Mean Carlson TSI values in South Dakota range from 39.0 to 92.4. Currently all lakes in South Dakota are compared to one another as if all could be restored to the same eutrophic condition (DENR 1998 and 1998a). This skews the trophic ranking by comparing lakes in the lesser-impacted Black Hills area to lakes in the heavily agricultural James River area. Some lakes in South Dakota's prairie ecoregions may never be able to reach the water quality condition of those lakes located in the Black Hills ecoregion. By comparing lakes within an ecoregion, attainable water quality targets can be set based on the best possible condition for that ecoregion.

1.2 Data and Methods

Data used for the comparison of lakes within and between ecoregions was compiled from all data available to the South Dakota Water Resource Assistance Program. Most of the data used came from the South Dakota Statewide Lakes Assessment, however, data from individual lake studies and the Department of Game Fish and Parks was also included.

Carlson's Trophic State Index (TSI) was used as the comparison index. Carlson's TSI relies on three standard parameters: total phosphorus, Secchi depth and chlorophyll-a (Equations 1.1, 1.2 and 1.3) respectively. The concentrations and measurements of these parameters were manipulated to fit an index scale of 0 to 100. Lower TSI values relate to nutrient-poor lakes and higher TSI values indicate nutrient-rich conditions (Carlson, 1977).

Due to spatial and temporal differences in data, WRAP set specific criteria to decrease variability and ensure data integrity. The following criteria were used:

Time Period: Most recent 10 years of data.
Depth: Surface or water column composites.
Seasonality: Samples collected between May 15 and September 15.
Data points: Minimum of five Trophic State Index values per lake.

Raw data from the WRAP database was applied to Carlson's equations and analyzed. The formulas used are provided below:

$$TSI\,(TP) = 10\left(6 - \left(\frac{LN\left(\frac{48}{TP}\right)}{LN\,2}\right)\right)$$ **Equation 1.1**

$$TSI\,(SD) = 10\left(6 - \left(\frac{LN\,SD}{LN\,2}\right)\right)$$ **Equation 1.2**

$$TSI\,(CHL) = 10\left(6 - \frac{2.04 - (0.68(LN\,CHL))}{LN\,2}\right)$$ **Equation 1.3**

TP = Total Phosphorus in μg/L
SD = Secchi depth in meters
CHL = Chlorophyll-a in mg/m^3

The mean TSI was calculated by averaging the TSI values for total phosphorus, Secchi depth and chlorophyll-a. The data was then sorted by ecoregion and ranked by increasing mean TSI. Figure 1.2 depicts mean TSI values for lakes within ecoregions.

Comparison of Mean TSI in All Ecoregions

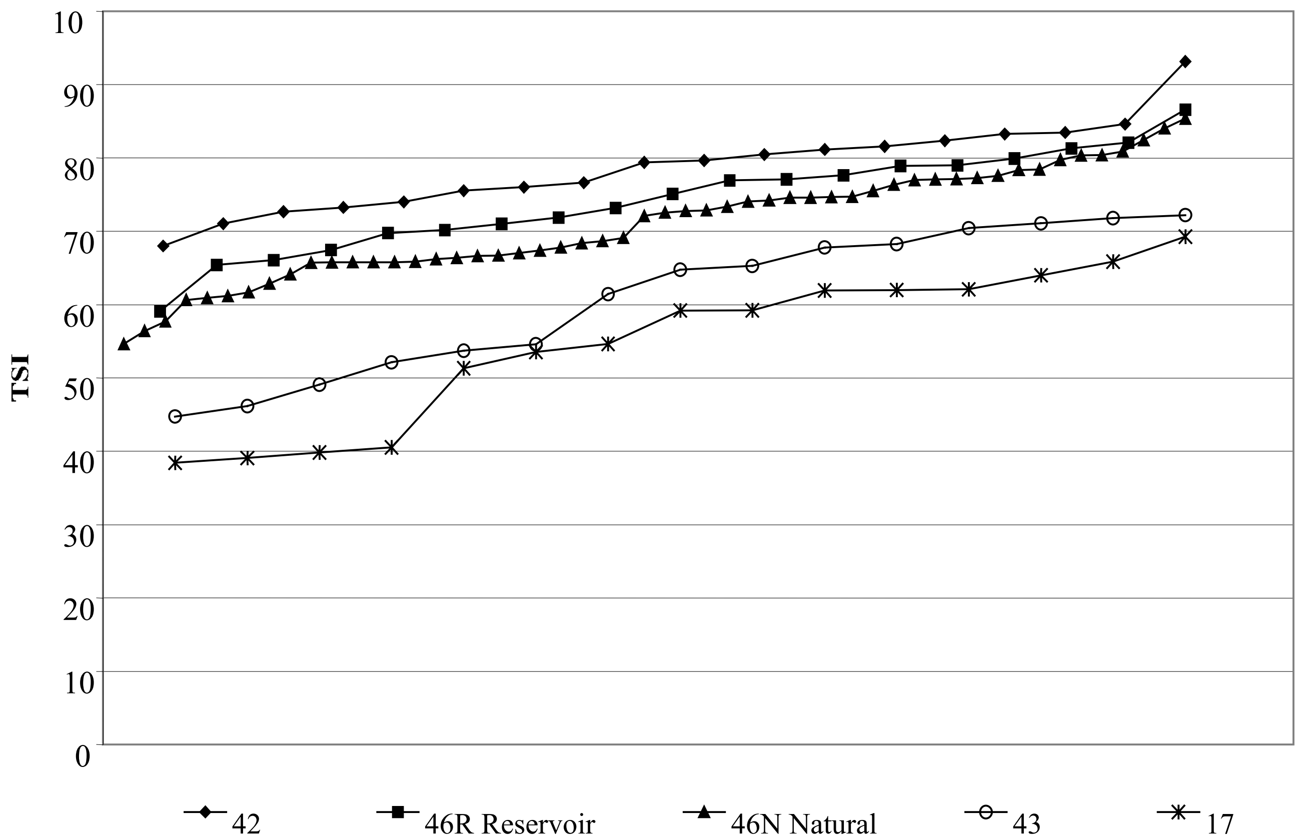

Figure 1.2. Mean TSI values by ecoregion sorted by increasing trophic states.

The Shapiro-Wilks test was used to test mean TSI values for normal distribution. Data was not found to be normally distributed ($p=<0.05$). Non-parametric (Mann-Whitney U) statistical tests were then performed on mean TSI values to determine any significant differences between and within ecoregions.

The determination of beneficial use support categories of fully supporting, partially supporting and non-supporting lakes was based mainly on natural breaks in the data. Fully supporting lakes had the lowest mean TSI values, partially and non-supporting lakes had TSI levels that supported algal blooms that could limit beneficial use. Wetzel (1983) states that a concentration of 0.020 mg/L (TSI 47.37) of total phosphorus can cause nuisance algal blooms. In South Dakota, *Anabaena*, *Aphanizomenon*, *Microcystis* and *Oscillatoria* spp. can be considered nuisance aquatic species. South Dakota Codified Law Article 74:51:01:09 states "*Materials which produce nuisance aquatic life may not be discharged or caused to be discharged into surface waters of the state in* *concentrations that impair a beneficial use or create a human health problem*." The partially supporting and non-supporting lakes receive and retain inlake phosphorus concentrations that causes nuisance algae blooms or have other sufficient organic matter to impair beneficial uses. Algae can form blooms that limit contact and immersion recreation and oxygen levels can be depleted. Reduced oxygen levels can stress fish or cause a "fish kill".

Two lakes, Lake Yankton (46R) and East Lake Eureka (42), receive water from unusual sources (mainly groundwater) unlike other monitored lakes. For this reason they were removed from the ranking and rated solely on their own water quality. Lake Yankton and East Lake Eureka are discussed separately within their respective ecoregions.

1.3 Results

Northern Glaciated Plains (46N and 46R)

Lakes in Ecoregion 46 (Northern Glaciated Plains) were separated into two groups, natural lakes (46N) and reservoirs (46R). A significant difference was found when the watershed to lake ratios were compared for the different waterbodies ($p<0.05$). In addition to the differences in watershed size (natural lakes mean – 87.8 acres and reservoirs mean – 675.5 acres) life expectancy for reservoirs is shorter than natural lakes. Natural succession (life expectancy) for most natural lakes generally takes thousands of years while the successional process in reservoirs is more rapid (<150 years). Although there was no significant difference between the mean TSI values of the two types of waterbodies ($p=0.105$), the reservoirs generally had higher TSI values (Table 1.1 and Figure 1.3). One purpose of sorting South Dakota lakes into ecoregions is to set reasonable targets for restoration. It was the best professional judgement of DENR staff to list the reservoirs in ecoregion 46 separate from the natural lakes because it will be more difficult to reverse the eutrophication process in reservoirs. The decision was based on the large difference in the watershed-to-lake ratios and the higher mean TSI values of the reservoir population.

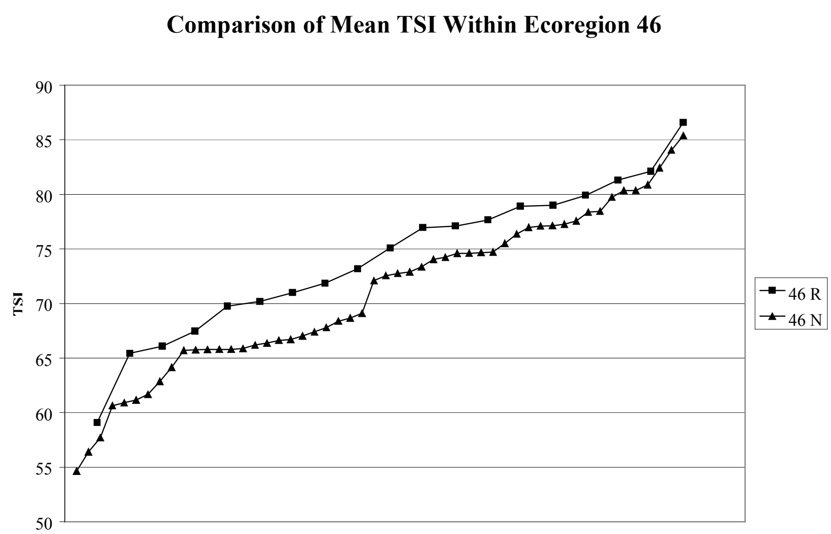

Figure 1.3. Mean TSI values within ecoregion 46N and 46R.

Table 1.1. Mean TSI, Secchi TSI, total phosphorus TSI and chlorophyll-*a* TSI values by ecoregion.

Ecoregion	Mean TSI	Parameters used to Calculate Mean TSI		
		Secchi TSI	Total Phosphorus TSI	Chlorophyll-*a* TSI
17	54.65	51.54	57.17	55.08
43	54.64	56.58	57.15	49.94
42	80.49	69.57	94.48	73.82
46N	70.23	65.43	76.09	67.98
46R	73.15	64.02	87.60	67.32

Support Determination for 46N

The mean TSI value for ecoregion 46N was 70.23 (Table 1.1). Determination of fully supporting, partially supporting and non-supporting status of lakes within ecoregion 46N was based on natural breaks in the data (Figure 1.4). Table 1.2 shows the numeric TSI range used for support determinations. Support for the natural breaks was provided by statistical analysis (Mann-Whitney – U). All natural breaks chosen within ecoregion 46N were significantly different ($p<0.05$).

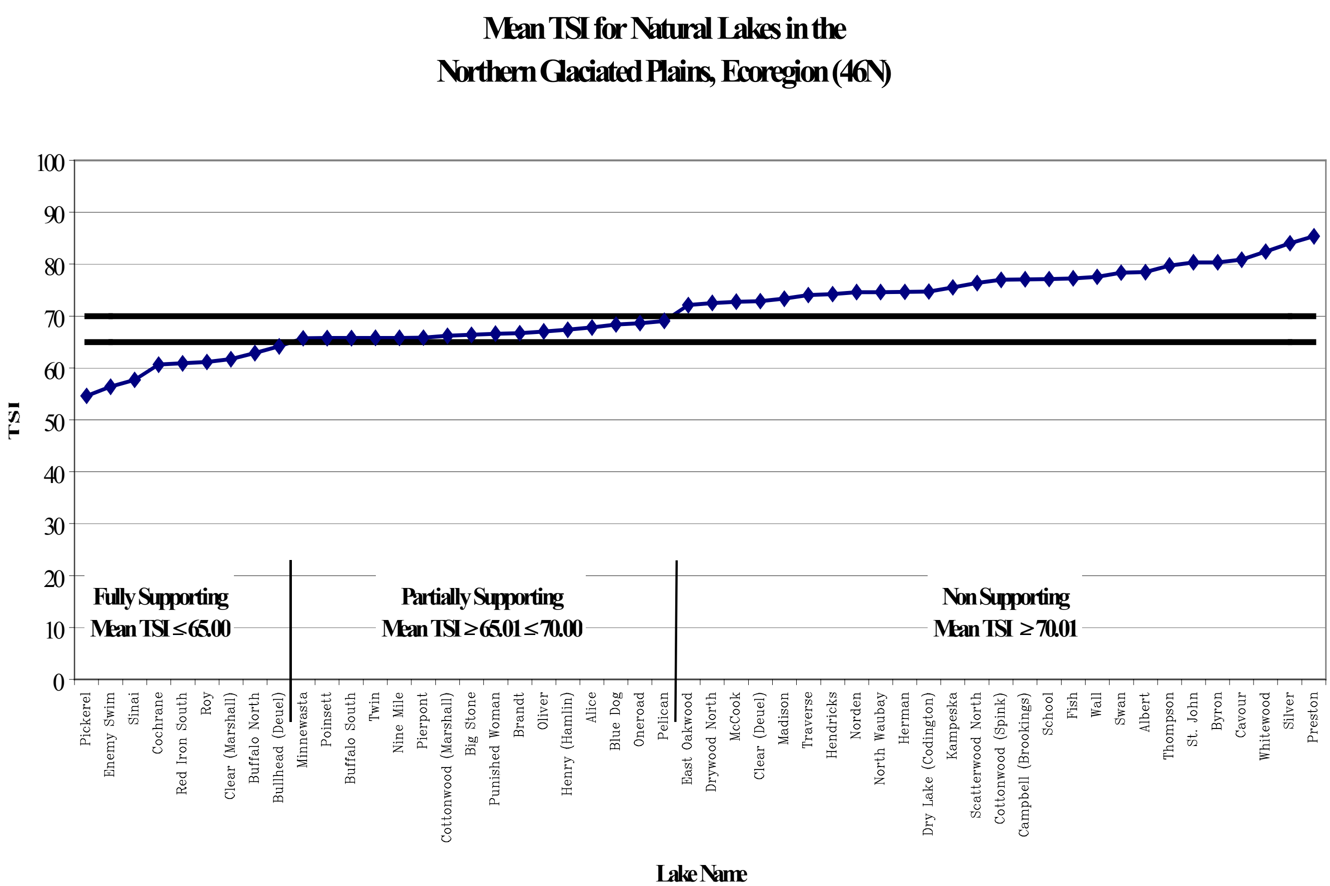

Figure 1.4. Mean TSI values and support breaks for ecoregion 46N.

Table 1.2. Ecoregion 46N support determination range.

Ecoregion 46N Support Determination			
	Fully Supporting	Partially Supporting	Non Supporting
TSI Range	≤ 65.00	≥ 65.01 – ≤ 70.00	≥ 70.01

Support Determination for 46R

The mean TSI value for ecoregion 46R was 73.15 (Table 1.1). Determination of fully supporting, partially supporting and non-supporting status of artificial lakes (reservoirs) within ecoregion 46R was based on natural breaks in the data (Figure 1.5.). Table 1.3 shows the numeric TSI range used for support determinations. Support for the natural breaks was provided by statistical analysis (Mann-Whitney – U). All natural breaks chosen within ecoregion 46R were significantly different ($p<0.05$).

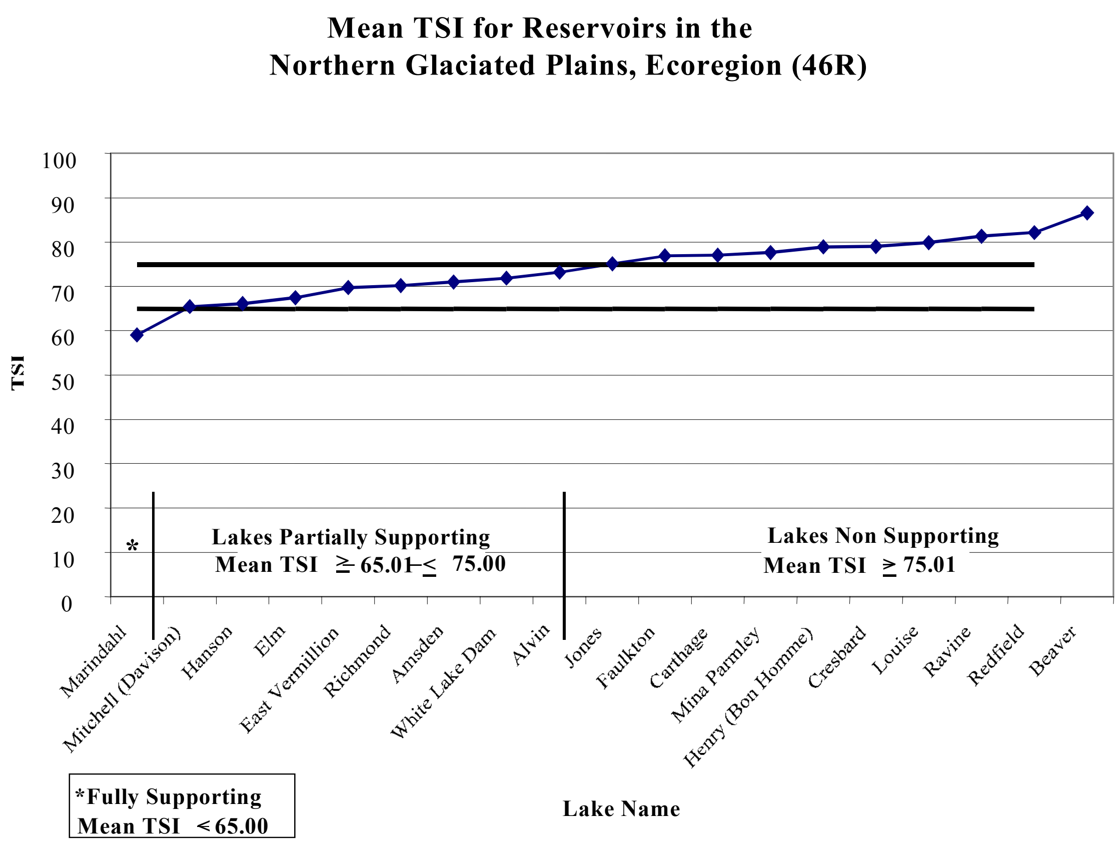

Figure 1.5. Mean TSI values and support breaks for ecoregion 46R.

Table 1.3. Ecoregion 46R support determination range.

Ecoregion 46R Support Determination			
	Fully Supporting	Partially Supporting	Non Supporting
TSI Range	≤ 65.00	≥ 65.01 – ≤ 75.00	≥ 75.01

One reservoir in this ecoregion, Lake Yankton, is fully supporting and was not included in Figure 1.5 because a major source of water for the lake is seepage from Lewis and Clark Reservoir. The filtered ground water has relatively low sediment and nutrient concentrations. Lake Yankton also has an overabundance of macrophytes. No other reservoir in the ecoregion has comparable water clarity or the extensive macrophyte coverage found in Lake Yankton. The mean TSI for Lake Yankton was 50.73.

Northwestern Glaciated Plains (42)

Ecoregion 42 is the Northwestern Glaciated Plains and generally covers central South Dakota east of the Missouri River (Figure 1.1). The mean TSI value for ecoregion 42 was 80.49 (Table 1.1). Ecoregion 42 was significantly different from other ecoregions ($p<0.05$). Mean total phosphorus TSI (94.48) and chlorophyll-a TSI (73.82) (increased total phosphorus results in larger algae blooms and chlorophyll-a concentrations) had the most influence on the overall mean TSI value. Some possible explanations for the increased TSI values are soil type and land use within ecoregion 42. Carlson's TSI values above 65 are considered hyper-eutrophic that indicates there are more than enough nutrients available to cause nuisance algae blooms. All lakes listed in Figure 1.6 were classified as hyper-eutrophic and none were given full support status.

The determination of fully supporting, partially supporting and non-supporting status of lakes within ecoregion 42 was based on natural breaks in the data (Figure 1.5). The numeric determination of fully supporting status in this ecoregion was $\leq$ 65.00, based on Carlson's trophic level (upper limit of eutrophic status) and trophic attainability within this ecoregion. Table 1.4 shows the numeric TSI range used for support determinations. Support for the natural break between partially supporting and non-supporting was provided by statistical analysis (Mann-Whitney – U). The natural break chosen within ecoregion 42 was significantly different ($p<0.05$).

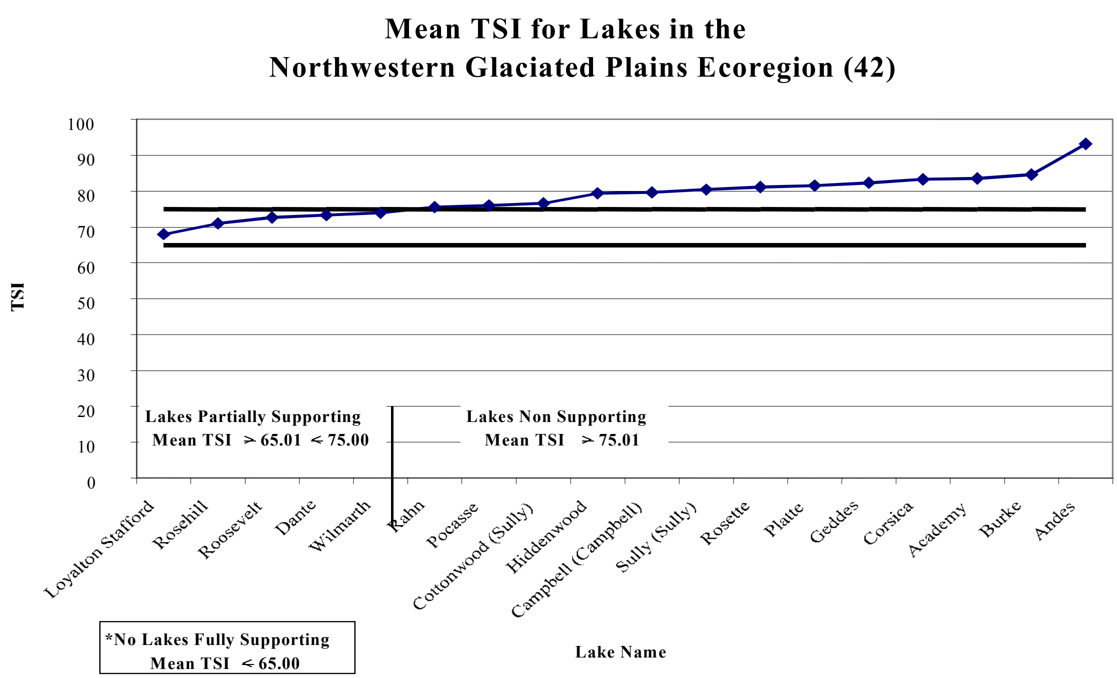

Figure 1.6. Mean TSI values and support breaks for ecoregion 42.

East Lake Eureka is located in this ecoregion; however, it is a shallow hand-dug lake basin and the water supply is of artesian origin, the lake was considered separately as fully supporting. All other lakes in this ecoregion except Cottonwood Lake and Lake Andes, which are now artificially controlled, are reservoirs. The mean TSI value calculated for East Lake Eureka was 64.26.

Table 1.4. Ecoregion 42 support determination range.

Ecoregion 42 Support Determination			
	Fully Supporting	Partially Supporting	Non Supporting
TSI Range	≤ 65.00	≥ 65.01 – ≤ 75.00	≥ 75.01

Northwestern Great Plains (43)

Ecoregion 43 is the Northwestern Great Plains and covers most of South Dakota west of the Missouri River (Figure 1.1). The mean TSI value for ecoregion 43 is 54.64 (Table 1.1). Ecoregion 43 was significantly different from the other ecoregions except ecoregion 17 ($p=0.101$).

The determination of fully supporting, partially supporting and non-supporting status of lakes within ecoregion 43 was again based on natural breaks in the data (Figure 1.7). Table 1.5 shows the numeric TSI range used for support determinations. Support for the natural breaks was provided by statistical analysis (Mann-Whitney – U). All natural breaks chosen within ecoregion 43 were significantly different ($p<0.05$).

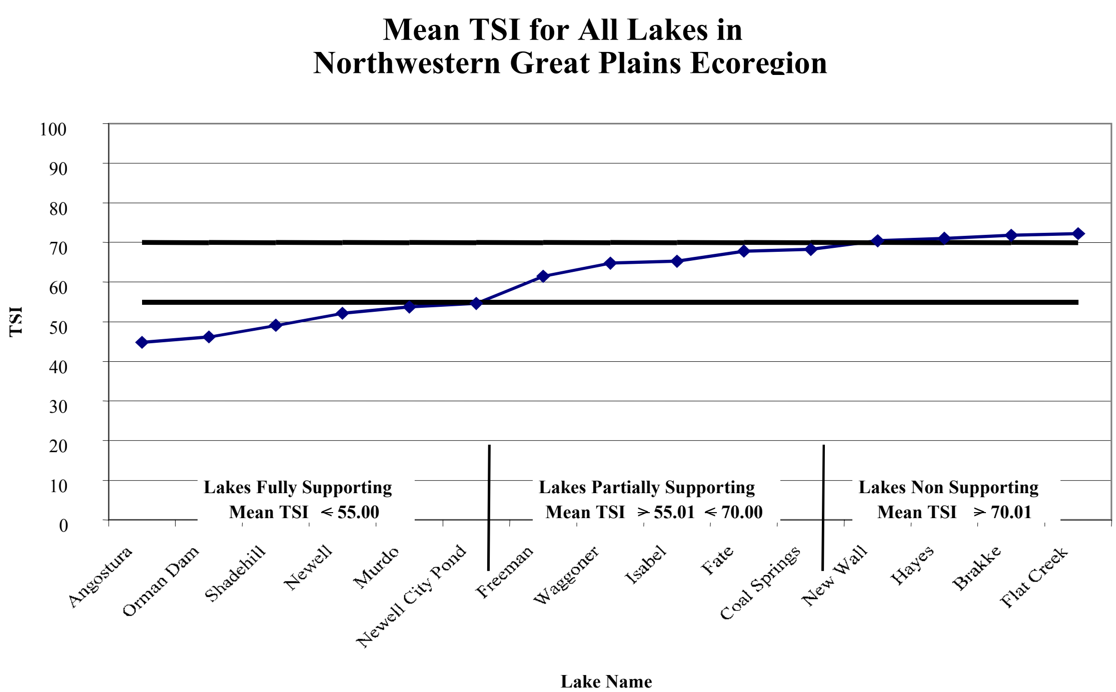

Figure 1.7. Mean TSI values and support breaks for ecoregion 43.

Table 1.5. Ecoregion 43 support determination range.

Ecoregion 43 Support Determination			
	Fully Supporting	Partially Supporting	Non Supporting
TSI Range	≤ 55.00	≥ 55.01 – ≤ 70.00	≥ 70.01

Middle Rockies (17)

Ecoregion 17 is the forested Black Hills area in western South Dakota (Figure 1.1). Ecoregion 17 has a mean TSI of 54.65 (Table 1.1). Ecoregion 17 showed significant difference from all of the other ecoregions except ecoregion 43 (p=0.101). Ecoregion 43 is the Northwestern Great Plains and covers most of South Dakota west of the Missouri River (Figure 1.1). The lakes in the two different ecoregions were not combined because of land use differences. Although the total phosphorus TSIs for the two ecoregions were similar, the mean TSI for ecoregion 17 was increased more by chlorophyll-*a* than by Secchi depth (Table 1.1). This indicates that nutrients/algae and not suspended sediment was affecting TSI values. The mean TSI in ecoregion 43 was increased more by Secchi depth than by chlorophyll-*a*, indicating suspended sediment was influencing the mean TSI more than nutrients/algae (Table 1.1).

The determination of fully supporting, partially supporting and non-supporting status of lakes within ecoregion 17 was based on natural breaks in the data (Figure 1.8). Table 1.6 shows the numeric TSI range used for support determinations. Support for the natural breaks was provided as before by statistical analysis (Mann-Whitney – U). All natural breaks chosen within ecoregion 17 were significantly different (p<0.05).

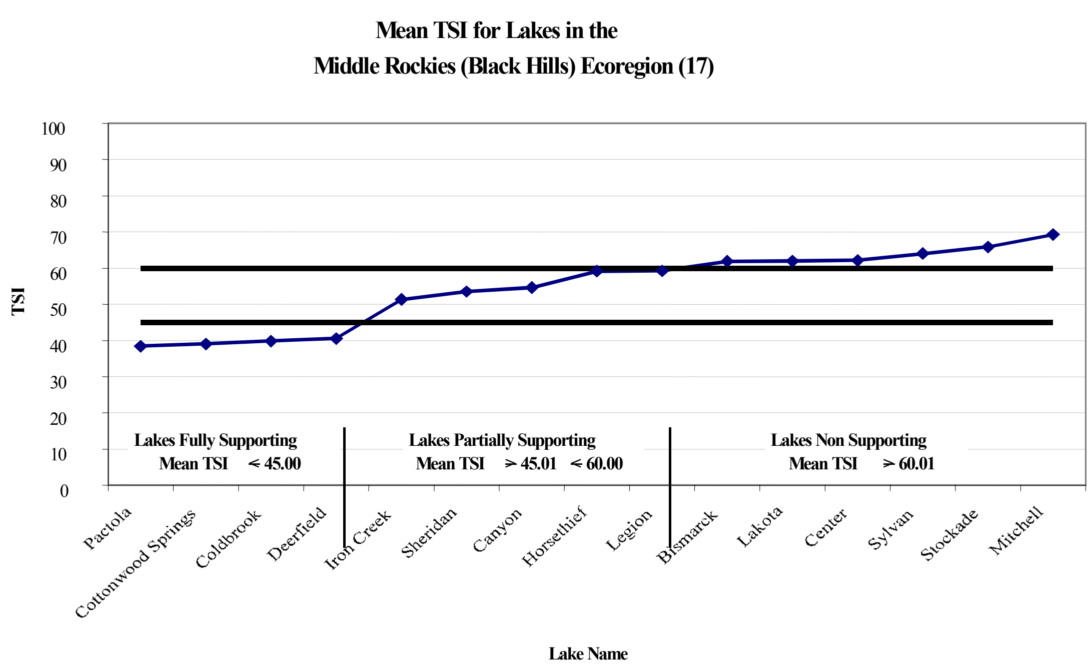

Figure 1.8. Mean TSI values and support breaks for ecoregion 17.

Table 1.6. Ecoregion 17 support determination range.

Ecoregion 17 Support Determination			
	Fully Supporting	Partially Supporting	Non Supporting
TSI Range	≤ 45.00	≥ 45.01 – ≤ 60.00	≥60.01

1.4 Conclusions

Table 1.7 summarizes the number of supporting, partially supporting and non-supporting lakes. The information presented in the previous paragraphs should help managers set attainable targets for water quality and restoration. There may be a few lakes within each ecoregion that may not be able to reach fully supporting status. In those cases, attainable site specific targets may have to be set.

South Dakota DENR does not feel it appropriate to list lakes which do not have sufficient data to fit the criteria mentioned in the methods section of this document. Once sufficient and credible data are collected, the lakes may be entered in the proper ecoregion list and support status determined.

Table 1.7. Lakes supporting, partially supporting and non-supporting by ecoregion.

Ecoregion	Fully Supporting	Partially Supporting	Non Supporting	Total
Middle Rockies (17)	4	5	6	15
Northwestern Great Plains (43)	6	5	4	15
Northwestern Glaciated Plains (42)	1**	7	10	18
Northern Glaciated Plains 46N-Natural	9	16	27	52
Northern Glaciated Plains 46R-Reservoirs	1*	8	10	19
Total	**21**	**41**	**57**	**119**

* Both Lake Yankton (46R) and **East Lake Eureka (42) were found to be fully supporting.

2.0 Biological Monitoring (Phytoplankton)

2.1 Introduction

The phytoplankton community is an essential component of the aquatic environment. These organisms represent the initial link in the food chain from which other biological communities, either directly or indirectly, derive their nutrient requirements. While adequate phytoplankton quantities are required for aquatic food chains, large populations of some taxa (*Anabaena*, *Aphanizomenon*, *Microcystis* and *Oscillatoria* spp.) can impair water quality.

Algae samples have been collected periodically from 127 lakes in South Dakota. Results were entered into a database and metrics calculated. All algae metrics were sorted by increasing eutrophication within each ecoregion according to mean Carlson TSI metrics (TSI (C)) (Secchi, total phosphorus and chlorophyll-*a*, Carlson 1977). Each algae metric within each ecoregion was analyzed for trends within and between ecoregions. The goal was to determine if any algae metrics correspond or complement the Carlson (1977) trophic state index (chemical and physical) sort.

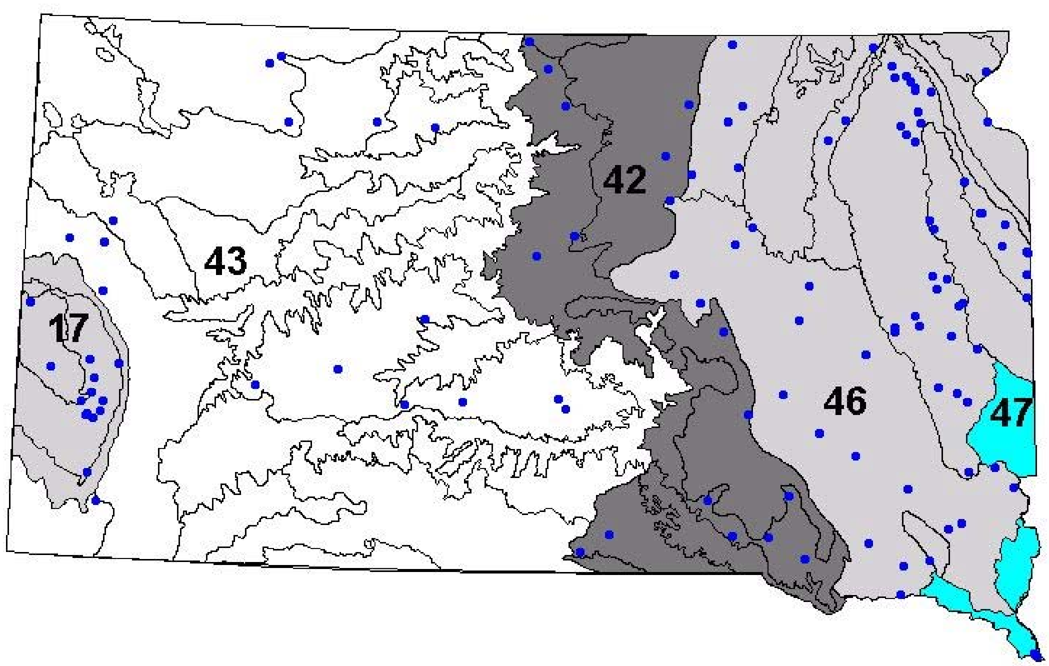

Figure 2.1. Location and distribution of lakes throughout South Dakota where algae samples were collected.

2.2 Methods

Algae samples were collected throughout South Dakota during statewide lake assessment sampling, special studies and lake assessment projects. The statewide lake assessment project samples lakes in a round robin manner, with an individual lake being sampled every fourth assessment year. Sample data used for ecoregion analysis were collected in 1979, 1989, 1998 and 1999. Algae sampling consisted of three composited surface samples, taken twice each sampling year, from different locations within a lake. All samples were preserved in the field with Lugol's solution and returned to the laboratory for analysis.

Algae identification was performed by separate individuals or consulting firms. Algae identifications were done by in-house personnel, Rick Fike (1979) and Andrew Repsys (1998, QA/QC 1999). Consultant identifications were performed by Keith E. Camburn (1989) and James Sweet of Aquatic Analysts (1999).

All results were entered into a database and analyzed. Phytoplankton metrics analysis consisted of percent cyanobacteria, percent AAM (Anabaena, Aphanizomenon and Microcystis), percent diatoms, percent centric diatoms, percent pennate diatoms, percent greens, percent colonial greens, percent chrysophytes, percent euglenophytes and percent dinoflagellates (suggested as potential phytoplankton metrics USEPA 1998). Other metrics included diversity (Shannon (base 10) and Simpson), evenness, Simpson dominance, TSI (B) (Biovolume) (Sweet 1986), Palmer (Genus) pollution index (Table 2.4) (Palmer 1969), total cells per milliliter and total blue green algae biovolume. Metrics developed in-house were the clean water index (values in Tables 2.1 and 2.2.), nitrogen-fixer index (C) (NFI (C), Cells per ml), nitrogen-fixer index (B) (NFI (B), Biovolume) and nitrogen-fixer index (Q) (NFI (Q), Quotient) (species in Table 2.3.).

Sweet (1986) derived a TSI (B) (Trophic State Index (Biovolume)) based on Carlson indices for Secchi, phosphorus and chlorophyll-a, (Carlson 1977) (Equation 2.1). The TSI (B) like the other TSI values range from 0 to 100, with lower values indicating lower trophic states. The formula for TSI (B) is:

$$TSI(B) = (\log_2 (B+1))*5 \qquad \textbf{Equation 2.1}$$

Where B is the phytoplankton biovolume in (micrometers^3 per milliliter) / 1000.

In-house metrics (clean water index, nitrogen fixer index (C), nitrogen fixer index (B) and nitrogen fixer index (Q)) were developed by Andrew Repsys, in-house phycologist. The clean water index utilizes species common to mesotrophic or slightly eutrophic lakes (Kummerlin 1998), and assigns numeric values to phytoplankton commonly associated with mesotrophic and slightly eutrophic lakes (Table 2.1).

For ecoregion 46, monitored waterbodies were separated into natural lakes (N) and reservoirs (R). This was the only ecoregion with a sufficient number of both types of surveyed waterbodies available to allow use of those two distinct categories. The other ecoregions contained mostly reservoirs with only two surveyed natural lakes.

Table 2.1. Clean water indicator species and corresponding values.

Taxa	Value
Cyclotella kuetzingiana	4
Cyclotella bodanica v. stellata	3
Cyclotella bodanica	3
Cyclotella comta	3
Cyclotella ocellata	3
Tabellaria fenestrata	3
Cyclotella michiganiana	2
Lagerheimia ciliata	2
Peridinium willei	2
Asterionella formosa	1
Eudorina elegans	1
Fragilaria crotonensis	1
Lyngbya birgei	1
Synedra radians	1

Values range from 1 to 4, with "one" indicating species found in eutrophic to slightly eutrophic (wider range of tolerance to eutrophication) lakes to "four" species found in oligotrophic to mesotrophic (narrower range of tolerance to eutrophication) lakes (Table 2.2). This index is based on species presence and not on density (cells/ml). When specific clean water species are found, the corresponding value is given and these values are summed for each lake. Generally, oligotrophic and mesotrophic lakes tend to have higher clean water index values than lakes that are slightly eutrophic to eutrophic.

Table 2.2. Clean water indicator categories.

Category	Value	Environmental Tolerance
Best	3 and 4	narrow tolerance
Good	2	wider tolerance
Fair	1	generalists

The nitrogen-fixer index (both cells/ml (C) (Equation 2.2) and biovolume/ml (B)(Equation 2.3)) is used to determine whether non-nitrogen-fixing filamentous blue-greens (notably *Oscillatoria* spp.) displace the common bloom-forming *Aphanizomenon* sp. and *Anabaena* sp. under increased nitrogen conditions. These indices were developed for eutrophic to hypereutrophic lakes (increased nitrogen levels) in South Dakota. Nitrogen fixing and non-nitrogen fixing filamentous species of blue green algae were used for these indices (Table 2.3). Nitrogen fixer index, NFI (both (C) and (B)) is a simple ratio:

$$\text{NFI (C)} = \frac{\text{Non-nitrogen-fixing filamentous blue green algae (cells/ml)}}{\text{Nitrogen-fixing filamentous blue green algae (cells/ml)}} \quad \textbf{Equation 2.2}$$

$$\text{NFI (B)} = \frac{\text{Non-nitrogen-fixing filamentous blue green algae (biovolume/ml)}}{\text{Nitrogen-fixing filamentous blue green algae (biovolume/ml)}} \quad \textbf{Equation 2.3}$$

Where biovolume is expressed in micrometers^3 / milliliter

Table 2.3. Filamentous blue green nitrogen -fixer index species

Non-Nitrogen Fixers	Nitrogen Fixers
Lynbya sp.	*Anabaena* sp.
Arthrospira sp.	*Anabaenopsis* sp.
Borzia sp.	*Aphanizomenon* sp.
Dasygloea sp.	*Aulosira* sp.
Hydrocoleum sp.	*Cylindrospermum* sp.
Microcoleus sp.	*Nodularia* sp.
Oscillatoria sp.	*Nostoc* sp.
Phormidium sp.	*Wollea* sp.
Porphyrosiphon sp.	
Romeria sp.	
Schizothrix sp	
. *Symploca* sp.	
Trichodesmium sp.	

Higher NFI values, (B) and (C) indicate non-nitrogen fixing filamentous blue greens out compete (more abundant) nitrogen-fixing filamentous blue greens under nitrogen enriched conditions. The NFI (C) values indicate a density ratio (cells/ml) and NFI (B) a volumetric ratio. The nitrogen fixer index (Q) (quotient) (Equation 2.4) is also a simple ratio of previously calculated NFI values:

$$\text{NFI (Q)} = \frac{\text{NFI (C)}}{\text{NFI (B)}} \qquad \textbf{Equation 2.4}$$

The NFI (Q) ratio discriminates between lakes that have more nitrogen-fixing cells with smaller biovolume (> 1.0) and lakes that have fewer nitrogen-fixing cells with larger biovolume (< 1.0).

2.3 Results

Northern Glaciated Plains (46N and 46R)

Fifty-two natural lakes and 19 reservoirs were monitored twice during the growing season of each of four years, 1979, 1989, 1998, and 1999 (Figure 2.2). Surface samples were collected at one or two mid-lake sites usually in June and August of each year.

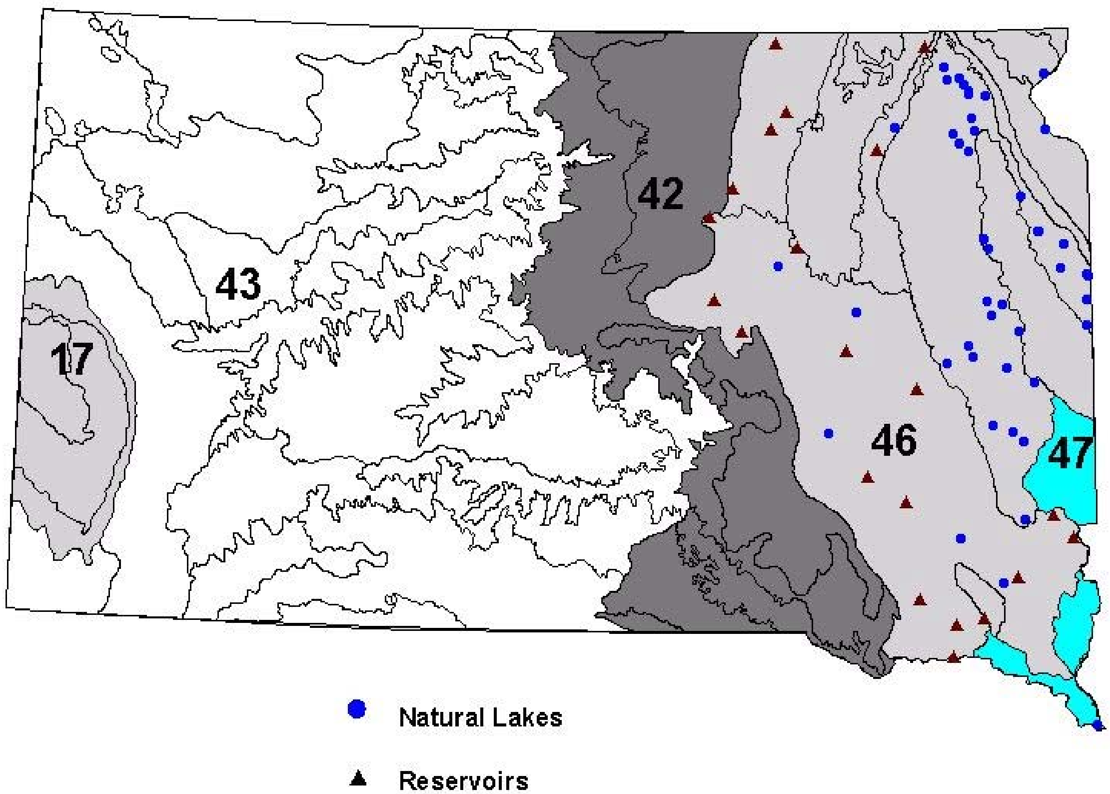

Figure 2.2. Distribution of reservoirs and natural lakes in Ecoregion 46

The great majority of the lakes in this ecoregion, which extends over the Big Sioux, Vermillion, and James River watersheds, are relatively small and naturally shallow due to the type of glacial action that went into their formation. Average depth during years of normal rainfall is less than 8 feet. The lake basins are often situated on sizeable watersheds comprised of nutrient-rich and salt-laden glacial soils that have been extensively developed for agriculture. Therefore, the potential for rapid natural and cultural nutrient-enrichment and siltation of these moderately sized, polymictic waterbodies has been considerable. The majority of the lakes are turbid and well-supplied with dissolved salts, nutrients, and organic matter mostly by runoff from agricultural and domestic sources. It has been estimated that nearly all of eastern state lakes and reservoirs are eutrophic to varying degrees.

Due in large part to the almost complete eutrophication of the lakes in this ecoregion, it is difficult to detect trends or meaningful differences between waterbodies based on only two or 3 samples collected from each lake per year. The annual cycles of algae in eutrophic lakes appear to be more dynamic than in lakes of lower trophic status. Populations of various algae species may rise to a high peak (bloom) then rapidly decline to low densities, all in a time period of only a week or two during a growing season. Seasonal fluctuations of algal populations in eutrophic lakes are more frequent and of greater magnitude and there is more rapid seasonal succession of algal species. In addition, the often-observed changes in size and composition of algal communities between years (year-to-year variability) are governed to a large extent by mostly unpredictable factors such as heterogeneous meteorological conditions (local rainfall patterns, seasonal temperatures, etc.). Moreover, each lake may respond differently to these factors based on its own individual characteristics. EPA estimated a minimum of six seasonal samples (or monthly samples) is required to adequately estimate mean populations and otherwise describe existing algal communities.

To determine any trends in algae species diversity among sampled waterbodies, 52 natural lakes and 19 reservoirs in the region were grouped separately against an increasing TSI values for 3 chemical parameters (mean of Secchi disk, total phosphorus, and chlorophyll-*a*).

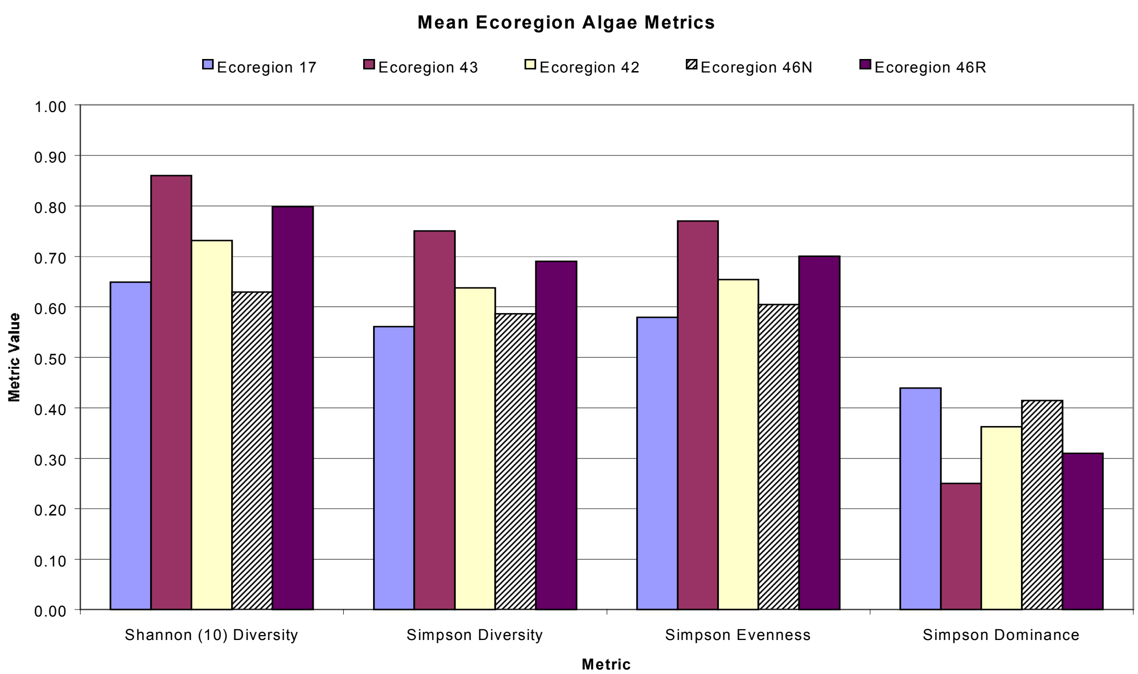

Figure 2.3. Mean Shannon (10) diversity, Simpson diversity, evenness and dominance values by level III ecoregions.

Shannon and Simpson diversity indices sorted by mean chemical and Secchi TSI values failed to reveal any pronounced trends in algae species diversity with increasing eutrophic status of the lakes

(Figures 2.3, 2.7N, 2.8N, 2.7R, and 2.8R,). Some literature sources suggest algal diversity increases, progressing from oligotrophic (nutrient-poor) lakes through mesotrophic waterbodies to reach a maximum value in moderately eutrophic lakes (e.g. TSI ~ 50 to 55). Diversity may then decline as lakes approach and attain hypereutrophic status (TSI >65) (Lepistö and Rosenström 1998).

During this survey, a moderate decline in diversity (trend line) was noted in the group of highly eutrophic lakes in the right half of Figures 2.7N and 2.8N. The 19 reservoirs compared on this basis showed no such effect (Figures 2.7R and 2.8R). The number of algal taxa (species richness) tallied for each of 19 waterbodies in 1998 seemed skewed toward the highly eutrophic natural lakes and reservoirs where a maximum of 60 and 67 taxa was recorded.

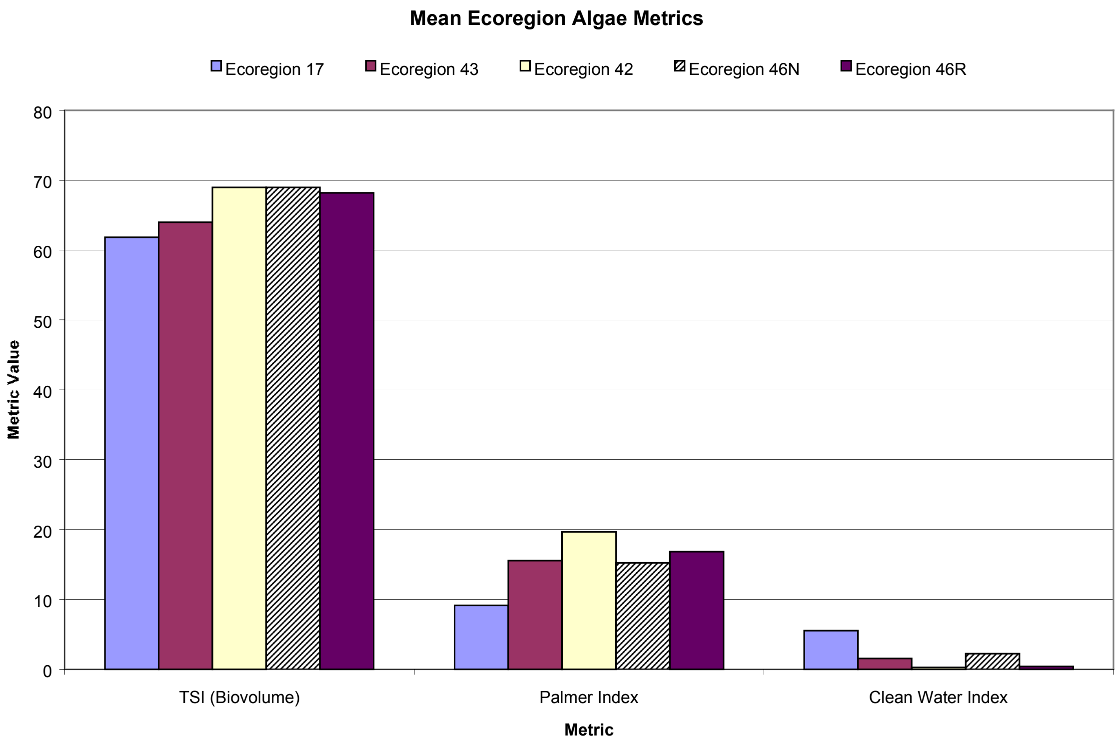

Figure 2.4. Mean TSI (B), Palmer index and clean water index metrics by level III ecoregions.

As typical lakes and reservoirs become more productive over time, increased numbers of algal cells per volume of water and increases in the biovolume or biomass of phytoplankton can be expected. The trend of increasing cell numbers is only suggested in Figures 2.9N and 2.9R, probably due to insufficient sampling as well as natural temporal and inter-lake variability. The algal biovolume index TSI (B) shows a slightly increasing trend in either lakes or reservoirs (Figures 2.10N and 2.10R). Widespread eutrophication in ecoregion 46 is illustrated by Figures 2.11N and 2.11R that show blue-green algae numerically comprising over 80% of total algae in 86% of the natural lakes and 58% of the monitored reservoirs. No trends in number or biovolume (Figures 2.11N, 2.11R, 2.12N and 2.12R) of blue-greens were evident with increasing eutrophication as estimated with chemical TSI values, except for a moderately increasing trend line in Figure 2.12R.

Aphanizomenon, *Anabaena*, and *Microcystis* species were the most numerous group of blue-greens (> 60% of total algae) in 38% of the natural lakes and nearly 47% of reservoirs (Figures 2.13N and 2.13R). The Palmer index (Table 2.4), which is a rough estimate of relative degree of eutrophication by the use of a number of eutrophic indicator algal genera (taxa tolerant of eutrophic conditions), also failed to show any kind of clear trend (Figures 2.14N and 2.14R). The trend line for natural lakes (Figure 2.14N) unexpectedly showed a downward slope, while the trend line for reservoirs (Figure 2.14R) showed only a slight positive incline.

Table 2.4. Palmer (Genus) pollution index values (Palmer 1969).

Genus	Pollution Index*
Anacystis sp.	1
Ankistrodesmus sp.	2
Chlamydomonas sp.	4
Chlorella sp.	3
Closterium sp.	1
Cyclotella sp.	1
Euglena sp.	5
Gomphonema sp.	1
Lepocinclis sp.	1
Melosira sp.	1
Micractinium sp.	1
Navicula sp.	3
Nitzschia sp.	3
Oscillatoria sp.	5
Pandorina sp.	1
Phacus sp.	2
Phormidium sp.	1
Scenedesmus sp.	4
Stigeoclonium sp.	2
Synedra sp.	2

* Increased values indicate greater pollution tolerance.

The 'clean-water' index, developed in-house, utilizes 14 algal species that have been found to be common in mesotrophic or moderately eutrophic waters (Kummerlin, 1998), and assigns a numerical value to each species based on its relative value as a indicator of good water quality (Table 2.1 and 2.2). This index seemed to show an expected decline in the presence of these taxa with increasing nutrient enrichment for natural lakes (Figure 2.15N) but not for reservoirs (Figure 2.15R). For the later, most of the values obtained were minimal (Figure 2.15R).

It has been known for some time that a number of filamentous blue-green algae (those with heterocysts) such as *Anabaena* and *Aphanizomenon* are capable of fixing (utilizing) atmospheric nitrogen, or can use dissolved molecular nitrogen (N_2) when the normal nitrogen species in a waterbody, such as nitrates and ammonium, are depleted. However, when the latter become overabundant (saturated) and light (through shading effects) becomes a limiting resource, selection of blue-green algae species in a turbid, highly eutrophic (hypertrophic) lake may favor the filamentous *Oscillatoria*-like genera which are more adapted to low illumination but are unable to

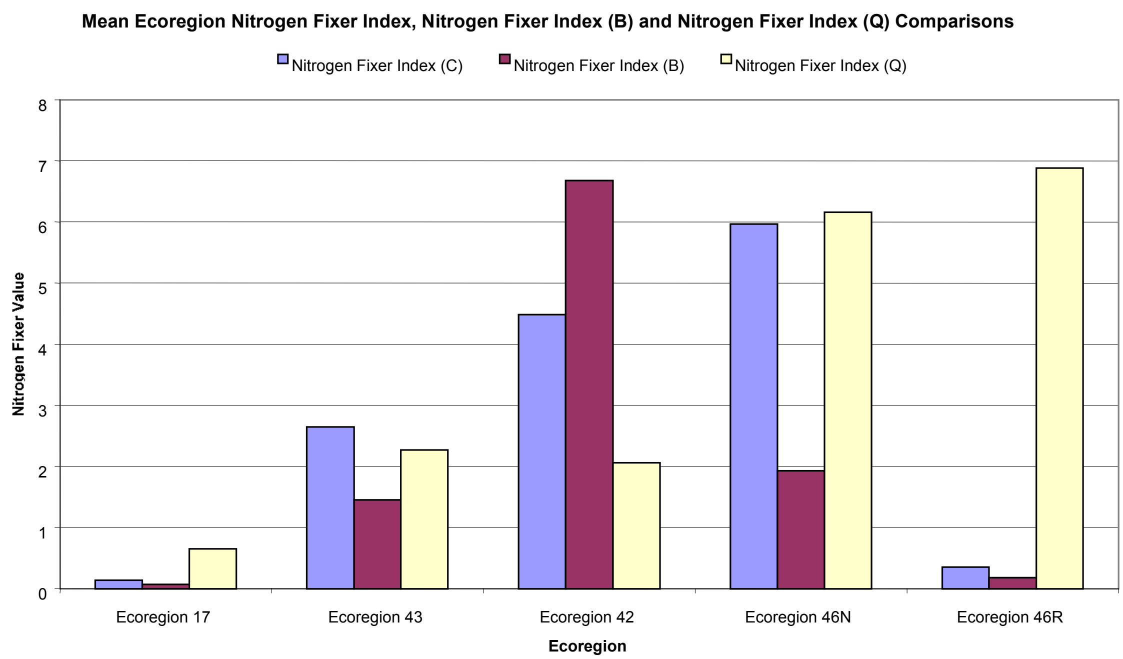

Figure 2.5. Mean nitrogen fixer index (cells/ml, biovolume and quotient) by ecoregion.

utilize atmospheric nitrogen (Padisak and Reynolds, 1998). Therefore, in a turbid, high nitrogen environment provided with sufficient phosphorus and carbon dioxide (carbon source), non-nitrogen fixing *Oscillatoria* and *Lyngbya* species (filaments with no heterocysts) may become much more numerous than *Anabaena* and *Aphanizomenon* spp.

To determine whether non-nitrogen fixing filamentous blue-greens (notably *Oscillatoria* spp.*)* may displace the common bloom-forming *Aphanizomenon* and *Anabaena* under high nitrogen conditions and low illumination, a simple ratio was used (non-fixing blue-greens/ N-fixing blue-greens) for both algal cell densities(cells/ml) and biovolume /ml. and grouped according to increasing eutrophication (TSI) of the lakes and, in addition, compared with local nitrogen and phosphorus values.

The results obtained, after comparing cell numbers of both algal groups in each lake, were mixed, except in some extreme cases of nitrogen-enrichment such as in Freeman Lake in ecoregion 43 and Lake Andes in ecoregion 42. Other factors not considered in this survey may have been involved, such as the total dissolved solids concentration in the surveyed lakes. However, this concept may have some validity with the collection of additional data and may be useful in characterizing those eutrophic lakes with *Oscillatoria* blooms as distinct from the more typical productive waterbodies where *Aphanizomenon* and *Anabaena* predominate (Figures 2.16N - 2.16N, 2.16R – 2.16R).

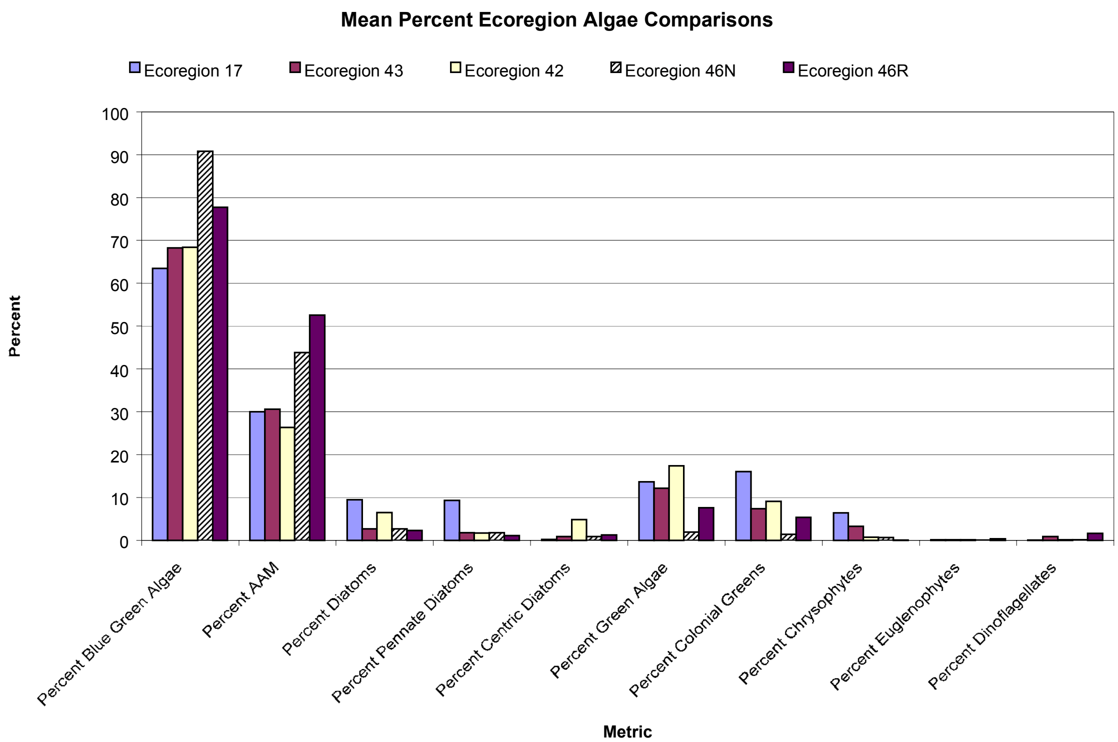

Figure 2.6. Mean algal percentage metrics by level III ecoregion

Percentage composition of the various other algal groups in the community of each lake and reservoir were determined and sorted against increasing eutrophication (TSI) as before (Figure 2.6). These groups included dinoflagellates, euglenophytes, chrysophytes, green algae, and diatoms (Figures 2.19N – 2.26N and 2.19R –2.26R). No meaningful trends could be ascertained with any confidence from an examination of most of these graphs. An exception may have been diatoms that showed a moderate increasing trend (for reservoirs) with increases in TSI values (Figure 2.24R). More data in this area needs to be collected in future years.

Northwestern Glaciated Plains (42)

This ecoregion adjoins the Missouri River in the approximate center of the state, running north to south then southeast parallel to the river course (Figure 2.1). Most of the region lies east of the Missouri River. This highland area is covered by glacial drift underlain by Pierre Shale and other formations. Drainage is westward to the Missouri River and eastward to the James River basin.

Sixteen of the18 monitored waterbodies in this ecoregion consist of small to medium-sized, highly eutrophic reservoirs (TSI range: 65-85; mean: 71). Most impoundments have a surface area less than 100 acres, and half are less than 50 acres. Two waterbodies, Lake Andes and Cottonwood Lake, are sizeable natural lakes (4,616 and 454 acres) that are also classified as highly eutrophic (hypertrophic) with TSI values of 79 and 74, respectively.

Shannon and Simpson diversity indices sorted on chemical, physical and Secchi TSI values seemed to show a slight to moderate upward trend (Figures 2.29 and 2.30). Since all of these waterbodies are in the hypertrophic range, probably little meaningful variation or distinctive characteristics in algal diversity can be discovered unless more intensive monitoring is conducted on these small reservoirs. The range of diversity values obtained suggested these waterbodies had a 'medium'or average diversity, roughly similar or slightly lower than that estimated for reservoirs in ecoregion 46. This conclusion is not supported by limited data obtained for species richness of the two ecoregions. Two of five reservoirs examined in 1998 had 62 and 63 taxa, with a mean of 49 taxa for all five impoundments, compared to an average 38 taxa for nine reservoirs in ecoregion 46. Simpson species evenness indices appeared to be similar for both ecoregions (Figures 2.27R and 2.49). The Palmer index for ecoregion 42 showed a definite upward trend with increasing TSI values, as contrasted with ecoregion 46 (reservoirs) where the positive incline of the trend line was more moderate (Figures 2.14R and 2.36).

As lakes and reservoirs become more productive, increases in algal numbers (density) and biovolume are usually observed. No definite trend of increasing cell numbers was evident from Figure 2.31, although the trend line showed a slight positive slope due solely to the large number of algal cells collected in Lake Platte. The algal biovolume index TSI (B) also showed no clear-cut trend. As mentioned above, all of these waterbodies are classified as hypertrophic based on Carlson's TSI values. The algal biovolume of these lakes is high and places 75% of the waterbodies in the hypertrophic category (TSI (B) >65). Overall TSI (B) appears slightly higher than that estimated for the reservoirs in ecoregion 46 (Figures 2.10R and 2.32).

The 'clean-water' index showed no trend in this ecoregion other than indicating low values (1.0) in several reservoirs, and the absence of these indicator algae in the majority of the waterbodies (Figure 2.37). This finding supports the evaluation that these reservoirs are highly eutrophic. More 'clean-water' algae were found in reservoirs of ecoregion 46, suggesting slightly more favorable environments in water quality than exist in ecoregion 42 (Figures 2.15R and 2.37).

The 'nitrogen-fixer' index charted on Figures 2.38 and 2.39 suggests a transition from nitrogen-fixing blue-green algae such as *Aphanizomenon* and *Anabaena* spp. to filamentous non-fixers (*Oscillatoria* and *Lyngbya* spp.) in the more nutrient-enriched lakes on the right of the figure, as discussed in the previous section.

The contribution of blue-green algae to the reservoir communities in this ecoregion was addressed in Figures 2.33, 2.34 and 2.35. Most of the trends were not readily interpretable. For example, total blue-green biovolume declined with increasing eutrophication (Figure 2.34) as did the percentage of blue-greens making up the total algae populations (Figure 2.33) including the percentage of *Aphanizomenon, Anabaena*, and *Microcystis* spp. (Figure 2.35). The latter trend may be due to the decline of the nitrogen-fixing algae and an incomplete replacement with non-fixing blue-greens in the more eutrophic reservoirs, as mentioned in the above paragraph. As a whole, blue-greens were somewhat less important, numerically (percentage, Figure 2.6) but slightly more important volumetrically (biovolume, Figure 2.4), in this ecoregion than in reservoirs of ecoregion 46. In ecoregion 42, blue-green algae numerically comprised over 80% of total algae in 47% of the reservoirs compared to 57% of the reservoirs in ecoregion 46 (Figures 2.33 and 2.11R). *Aphanizomenon, Anabaena,* and *Microcystis* spp. were the most numerous group of blue-greens (>60% of total algae) in only 7% of local reservoirs compared to 43% of reservoirs in ecoregion 46. The small percentage in the former is due to the replacement of those common bloom species by *Oscillatoria* spp., *Lyngbya* spp. and other blue-green taxa.

The percentage composition of the various other algal groups in the community of each lake and reservoir were determined and sorted against increasing eutrophication (TSI) as for ecoregion 46. As before, the groups included dinoflagellates (armored flagellated algae), chrysophytes (yellow-brown flagellates), euglenophytes (*Euglena, Phacus, Trachelomonas,* and others), green algae, and diatoms (Figures 2.41, 2.43, 2.42, 2.44 and 2.46). Chrysophytes did not appear to show a noteworthy trend with increasing TSI (Figure 2.43). Weak to moderate positive trends were in evidence for centric diatoms, green algae, and euglenophytes (Figures 2.47, 2.44 and 2.42). A negative trend was shown by dinoflagellates (Figure 2.41). These patterns suggested that centric diatoms, green algae, and euglenophytes tended to be more important in the more highly eutrophic waterbodies of this ecoregion, while the opposite held true for dinoflagellates. Euglenophytes tend to be most common in organically-polluted waters while green algae as a group prefer nutrient-enriched situations. The nutrient preferences of centric diatoms vary with individual species. For example, while the genus *Cyclotella* is generally representative of good water quality (e.g. mesotrophic lakes), *C. meneghiniana* becomes abundant in some highly eutrophic South Dakota lakes (e.g. Geddes and Corsica Lakes), one of very few species of the genus to show a preference for eutrophic waters. This may explain the overall increased mean percentage of centric diatoms in this ecoregion (Figure 2.6).

Northwestern Great Plains (43)

The unglaciated prairie rangeland that extends over most of the western half of South Dakota has few natural lakes but there are a number of man-made lakes, numerous small farm ponds (stock dams), and three large reservoirs. Understandably, the surface terrain of this large ecoregion is variable. A series of smooth hills and ridges with rounded tops represent major land features of the central area. Elevation increases to the north with a series of plateaus and isolated buttes representing prominent geographic features in that region. The Missouri River forms the dividing line between two major land-use practices- cropping in the east and livestock grazing in the west. Despite considerable grazing use, and rapid conversion of native prairie to cropland, there still exist extensive areas of high-quality grassland in western South Dakota. NRCS estimated that erosion rates on cropland soils may range from two to eight times higher than the erosion rates for the same soils in native grassland in good condition. Therefore, nutrient and sediment loads to the reservoirs in this ecoregion can be expected to be appreciably less than those impacting lakes further east where land is utilized primarily to grow crops.

Shannon and Simpson diversity indices sorted on chemical, physical and Secchi TSI values showed a moderate upward trend (Figures 2.51 and 2.52). The range of diversity values obtained suggested these reservoirs had, overall, average algae species diversity, moderately higher than ecoregion 42 and comparable to that of the reservoirs in ecoregion 46 (Figures 2.29 and 2.7R). More balanced algae populations in this ecoregion than those further east are suggested by the Simpson evenness index (Figure 2.71). However, a smaller number of species was collected here in the five reservoirs examined during 1998 (mean: 30 taxa). The Palmer index showed a slightly declining trend line suggesting there was little difference in the number of eutrophic indicator taxa with increasing TSI values (Figure 2.58). No apparent trends were evident in total algal cells/ml. and algal biovolume index TSI (B) sorted against increasing physical and chemical TSI values (Figures 2.53 and 2.54). However, overall algal densities (cells/ml) and biovolume were lower than those found in the two ecoregions to the east (42 and 46) (Figures 2.4 and 2.6). This is in line with the change in land use as noted above. The differences would be greater than shown in the latter figures if Freeman Lake were excluded from consideration. For the last decade, this moderately sized reservoir has been uniquely and severely impacted by extremely high nitrate (>10ppm) and dissolved solids levels originating in seepage from shallow ground water in the vicinity of the lake. This fertilization has apparently had the effect of producing very large algal populations compared to the other monitored waterbodies in this ecoregion (Figure 2.53).

In ecoregion 43, blue-green algae numerically comprised over 80% of total algae in 40% of the reservoirs compared to 47% and 57% of the reservoirs in ecoregions 42 and 46, respectively (Figures 2.6, 2.11N, 2.11R, 2.33 and 2.55). *Aphanizomenon, Anabaena,* and *Microcystis* spp. were the most common group of blue-greens (> 60% of total algae) in 20% of local reservoirs compared to 6% in ecoregion 42, and 47% in reservoirs of ecoregion 46 (Figures 2.13N, 2.13R, 2.30 and 2.57). Over all, blue-green biovolume was smaller here than in reservoirs of the previous ecoregions, as expected (Figure 2.6). The three ecoregions discussed so far differed with respect to biovolume trends. This ecoregion showed a moderate increase in biovolume of total blue-greens with increasing TSI values, (Figure 2.56) while that in ecoregion 42 registered a decline and only a slight increase for ecoregion 46R (Figures 2.34 and 2.12R). The cause of these differences is unknown at this time.

The percentage composition of the other algal groups were determined and sorted against increasing eutrophication for the reservoirs in this ecoregion. Euglenophytes and total green algae showed a moderate increase (as a percentage of the total algae) with increasing TSI values, similar to the trends observed for ecoregion 42 (Figures 2.42, 2.44, 2.64 and 2.66). No trends could be determined with any confidence for total diatoms, dinoflagellates, or chrysophytes, partly due to the erratic nature of that data and insufficient samples available (Figures 2.68, 2.63 and 2.65).

The ‘clean-water’ index showed a good distribution of indicator species and suggested there was a decline with increasing eutrophication in the ‘west-river’ ecoregion (Figure 2.59). The distribution of indicator species was similar to that of the reservoirs in ecoregion 46 but much better than in ecoregion 42 (Figures 2.4, 2.15R and 2.37).

No trends were evident in the ‘nitrogen-fixer’ indices (biovolume and cells) presented in Figures 2.61 and 2.60. The nitrogen fixer quotient index indicated an increasing trend of small-celled, non-nitrogen fixing algae (Figure 2.62). Except for Freeman Lake previously discussed, most ratios were small. The reasons for this are not clear, except to suggest a lower level of eutrophication for the waterbodies in this ecoregion.

<u>Middle Rockies (17)</u>

This ecoregion encompasses the Black Hills, an isolated area of granitic uplift in the far west of the state, approximately 100 miles long and 60 miles wide, and rising nearly 3000 feet above the surrounding plains. Most of the Black Hills is covered with ponderosa pine forest. The Black Hills potentially has some of the best surface water quality in the state. This in large part is due to a cooler climate during the growing season, and more rainfall than in the surrounding plains as a result of greater elevation and forest cover. Also contributing importantly to better water quality in this region is the nature of local bedrock formations which are much less erodible than the highly erosive and leachable marine shales and badlands on the surrounding plains. The'lakes'in the Black Hills are all artificial impoundments, mostly small in surface area, with small drainages, and ,unlike prairie lakes, protected from strong winds by dense surrounding forest and hilly terrain. Man-induced impacts to water quality in the region have been lumbering, mining, limited livestock grazing, recreational activities, road construction, and treated wastewater, salts, and incidental chemical effluents from private residences, commercial enterprises, and towns.

Shannon and Simpson diversity sorted on chemical and physical TSI values disclosed a moderate upward trend similar to that obtained for the western plains (43) (Figures 2.73, 2.74, 2.51 and 2.52). However, overall diversity here was somewhat lower than obtained for ecoregion 43 (Figure 2.3). Simpson evenness values were also lower in ecoregion 17 (Figures 2.93 and 2.3). The reasons for the lower values are not easily explainable since water quality in the Black Hills is at least as good as that in ecoregion 43. Mean TSIs for the two regions were almost identical (Table 1.1). Further sampling may help resolve some of these questions. The Palmer eutrophication index showed a slight incline which suggests there was little change in the number of indicator taxa with increasing TSI values (Figures 2.80 and 2.4). The average number of indicator taxa (Table 2.4) in the Black Hills was the lowest of the four ecoregions considered, suggesting less enrichment of local waters (Figure 2.4). No interpretable trends were evident in total algal cells/ml and algal biovolume index TSI(B) (Figures 2.75 and 2.76). Average algae densities and biovolume were the smallest of the four ecoregions surveyed, which may also reflect relatively less enrichment of the waters in this region.

Blue-green algae made up over 80% of total algae in 46% of the monitored reservoirs, compared to 40% in ecoregion 43 (Figures 2.77 and 2.55). Blue-green biovolume trends were not interpretable due to the large algal volume estimated for Iron Creek Lake (Figure 2.78). *Aphanizomenon, Anabaena, and Microcystis* were the most common group of blue-greens (> 60% of total algae) in 31% of local waterbodies compared to 20% in ecoregion 43 (Figures 2.79 and 2.57). Those taxa (primarily *Anabaena* spp.) increased in importance with increasing eutrophication (Figure 2.79). Ecoregion 17 also had the lowest mean percentage or blue green algae and the highest percent of total and pennate diatoms when compared to other ecoregions (Figure 2.6). This indicates that Black Hills lakes are less eutrophic than prairie lakes.

The 'nitrogen-fixer' indices presented in Figures 2.82, 2.83 and 2.84 indicated no trend. Mean nitrogen fixer indices were lowest in ecoregion 17 compared to other ecoregions (Figure 2.5).

Ratios for most reservoirs were too small to be charted on the graphs. Moderately small ratios appeared for Sheridan and Stockade Lake, two of the larger eutrophic reservoirs in the Black Hills.

The 'clean-water' index for ecoregion 17 showed a good distribution of indicator taxa and suggested a decrease in clean-water values with increasing eutrophication, similar to the index for ecoregion 43 (Figures 2.81 and 2.59). Pactola Reservoir has many more indicator taxa than indicated by the small ratio in Figure 2.81. Further sampling and resolution of the pertinent diatom indicator species should produce a ratio similar to that of Deerfield Reservoir. Similar results should be obtained for Coldbrook Reservoir when sample analysis is completed for that waterbody.

The percentage composition of the other common algal groups was determined and sorted against increasing eutrophication for waters in ecoregion 17. Total green algae and euglenophytes increased with increasing TSI values, similar to their response in ecoregions 42 and 43 (Figures 2.88, 2.86, 2.44, 2.42, 2.66 and 2.68). At the same time, chrysophytes and centric diatoms declined, and dinoflagellates showed no trend (Figures 2.87, .2.91 and 2.85).

2.4 Conclusions

Phytoplankton communities from lakes of four major ecoregions in SD were analyzed qualitatively and quantitatively for the years 1979, 1989, 1998, and 1999. Comparisons of algal communities were drawn between lakes of a single ecoregion and between ecoregions. Findings from the study are summarized below:

1. 574 taxa which represent 156 genera in seven algal divisions were collected. Blue-green algae were the most abundant group in South Dakota lakes. Diatoms and green algae were the most diverse groups encountered.

2. Total algal biovolume was highest in natural lakes of ecoregion 46 and reservoirs of ecoregion 42. Biovolume was lowest in ecoregion 17 (Middle Rockies, Black Hills).

3. 'Clean-water' index was lowest in ecoregion 42 and highest in ecoregion 17 (Figure 2.4).

4. The Palmer index for eutrophication was highest for ecoregion 42 and lowest in ecoregion 17 (Figure 2.4).

5. Ecoregion 17 had the lowest percentage of blue-green algae whereas ecoregion 46N had the largest percentage (Figure 2.6).

6. The above four indices suggest ecoregion 17 may have the best water quality of the four ecoregions surveyed, and ecoregion 42 some of the worst. This evaluation supports water chemistry analyses carried out in the same waterbodies from 1989 to1999.

7. Shannon (10) algal diversity was highest in ecoregion 43, mainly due to more balanced algae populations (high evenness values) in this region (Figure 2.3). Diversity was lowest in the natural lakes of ecoregion 46, probably the result of large populations of a few blue-green species.

8. The 'nitrogen-fixer' indices were highest in ecoregion 42 (for biovolume) and in ecoregion 46 for numerical abundance (algal cells/ml) of the pertinent blue-green taxa. Smallest indices were recorded for ecoregion 17. A major purpose of these indices was to separate highly eutrophic lakes and reservoirs into 'Oscillatoria types' and the more typical 'Aphanizomenon/ Anabaena type' waterbodies for further evaluation. A listing of exclusively nitrogen fixer, non-nitrogen fixer and no filamentous fixers or non-fixer lakes by ecoregion is provided in Table 2.5.

9. Percent green algae and euglenophyte metrics showed positive responses to increased eutrophication in three out of four ecoregions (17, 43 and 42) (Figure 2.6).

10. Since frequent changes in algae populations' size and composition are known to be typical of eutrophic lakes in the course of a year, sampling frequency needs to be increased to properly describe those dynamic communities.

Table 2.5. Nitrogen Fixer Index lakes with Fixers, Non-Fixers or None.

Nitrogen Fixer Lakes

Lake Name	Ecoregion
Bismark	17
Canyon	17
Cold Brook	17
Deerfield	17
Iron Creek	17
Horsethief	17
Legion	17
Lakota	17
Sylvan	17
Hiddenwood	42
Platte	42
Pocasse	42
Roosevelt	42
Rosehill	42
Sully	42
Angostura	
Hayes	43
Murdo	43
Newell City Pond	43
Waggoner	43
Big Stone	46N
Blue Dog	46N
Cavour	46N
Clear Lake	46N
Cottonwood	46N
Dry Lake	46N
Hendricks	46N
Kampeska	46N
Alice	46N
Minnewasta	46N
Nine Mile	46N
Norden	46N
Scatterwood (North)	46N
Oneroad	46N
Pelican	46N
Punished Womans	46N
Sinai	46N

Table 2.5. Nitrogen Fixer Index lakes with Fixers, Non-Fixers or None (continued).

Nitrogen Fixer Lakes

Lake Name	Ecoregion
St. John	46N
Wall	46N
Cresbard	46R
Dakotah	46R
Elm	46R
Louise	46R
Marindahl	46R

Non-Nitrogen Fixer Lakes

Andes*	42
Freeman**	43

No Filamentous Fixers or Non-Fixers

Isabel	43
Jones	46R

* 1979
** 1998

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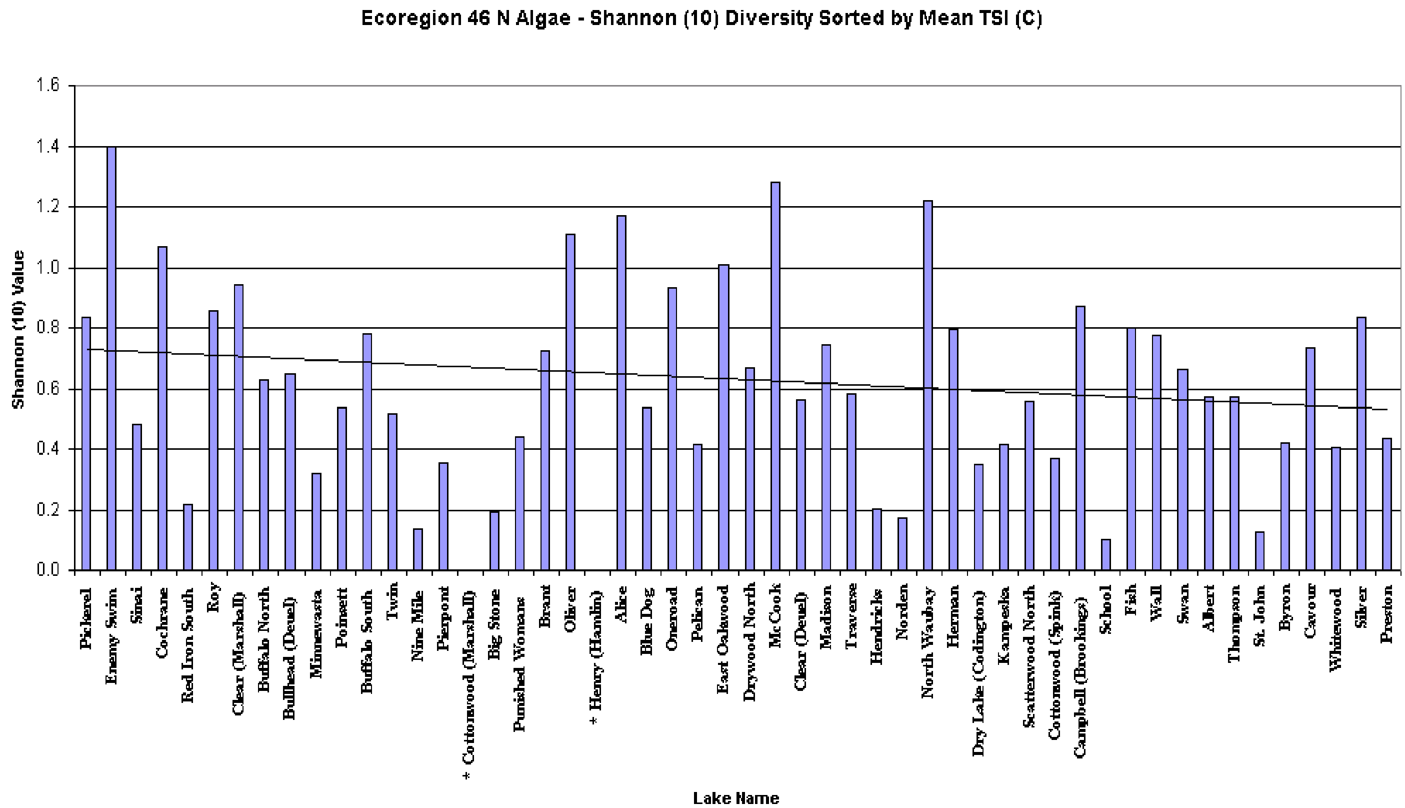

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Figure 2.7N. Ecoregion 46N Algae – Shannon (10) diversity sorted by mean TSI (C).

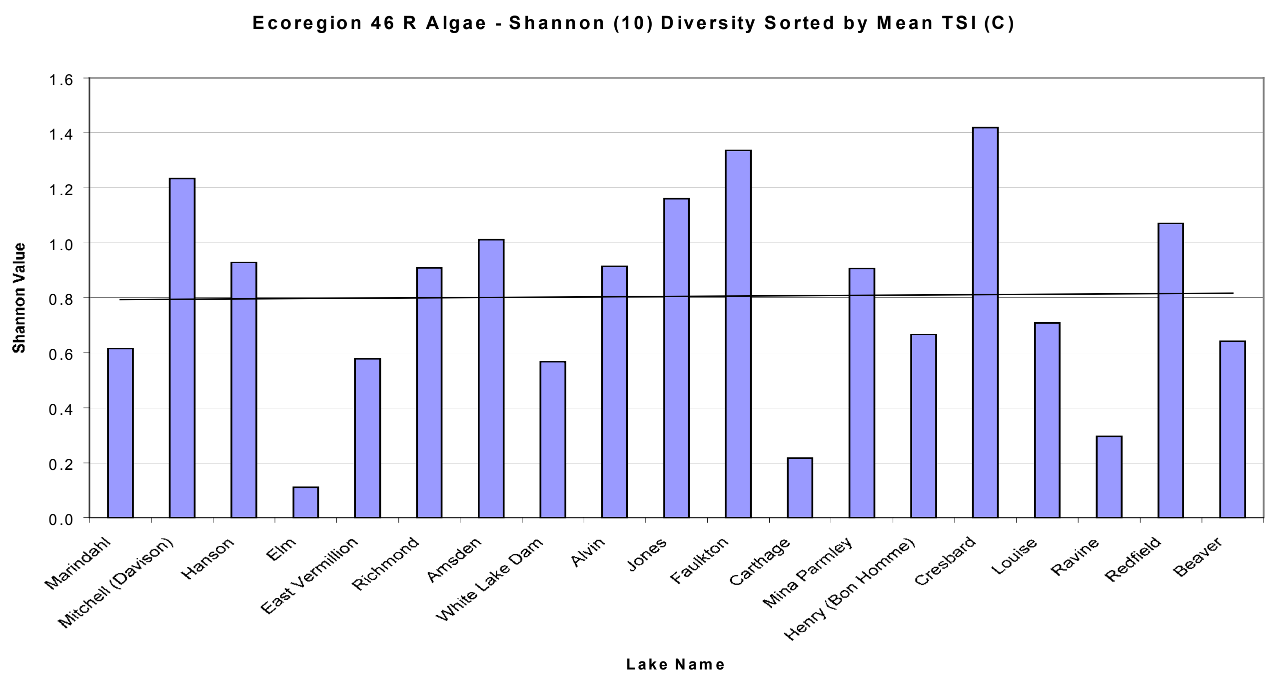

Figure 2.7R. Ecoregion 46R Algae – Shannon (10) diversity sorted by mean TSI (C).

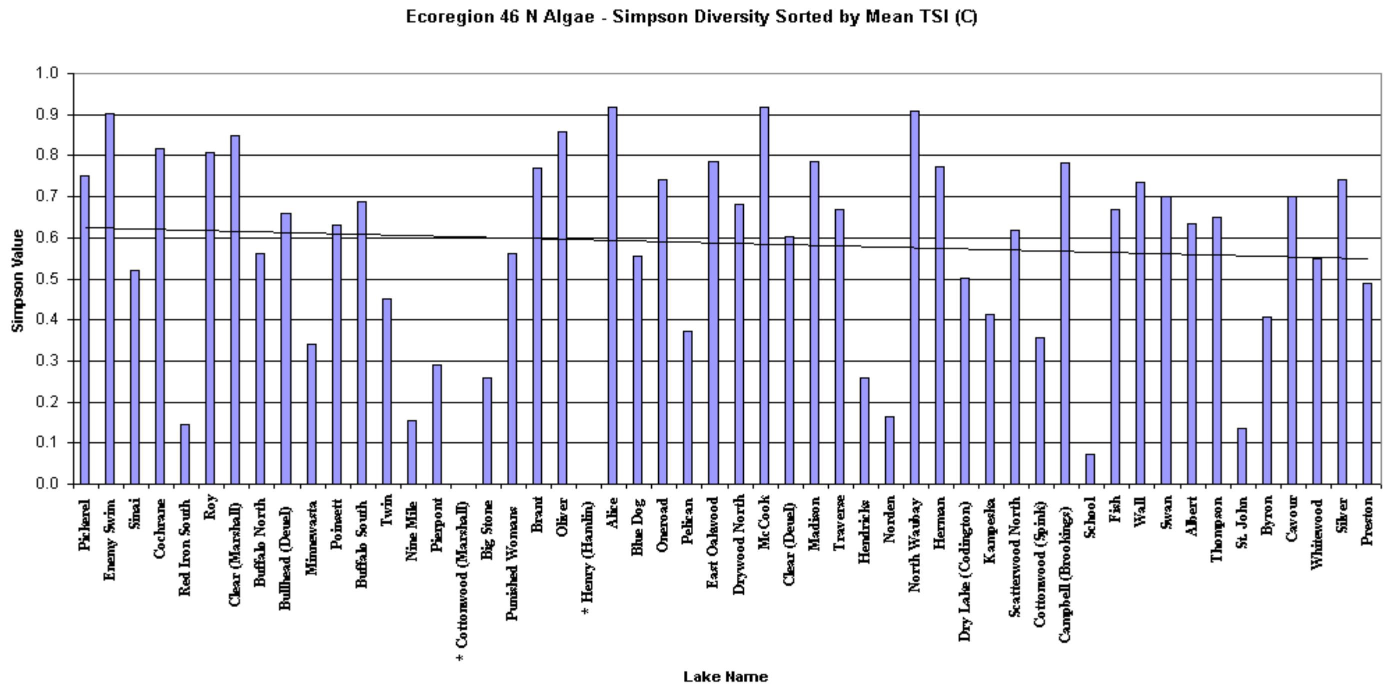

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Figure 2.8N. Ecoregion 46N Algae – Simpson diversity sorted by mean TSI (C).

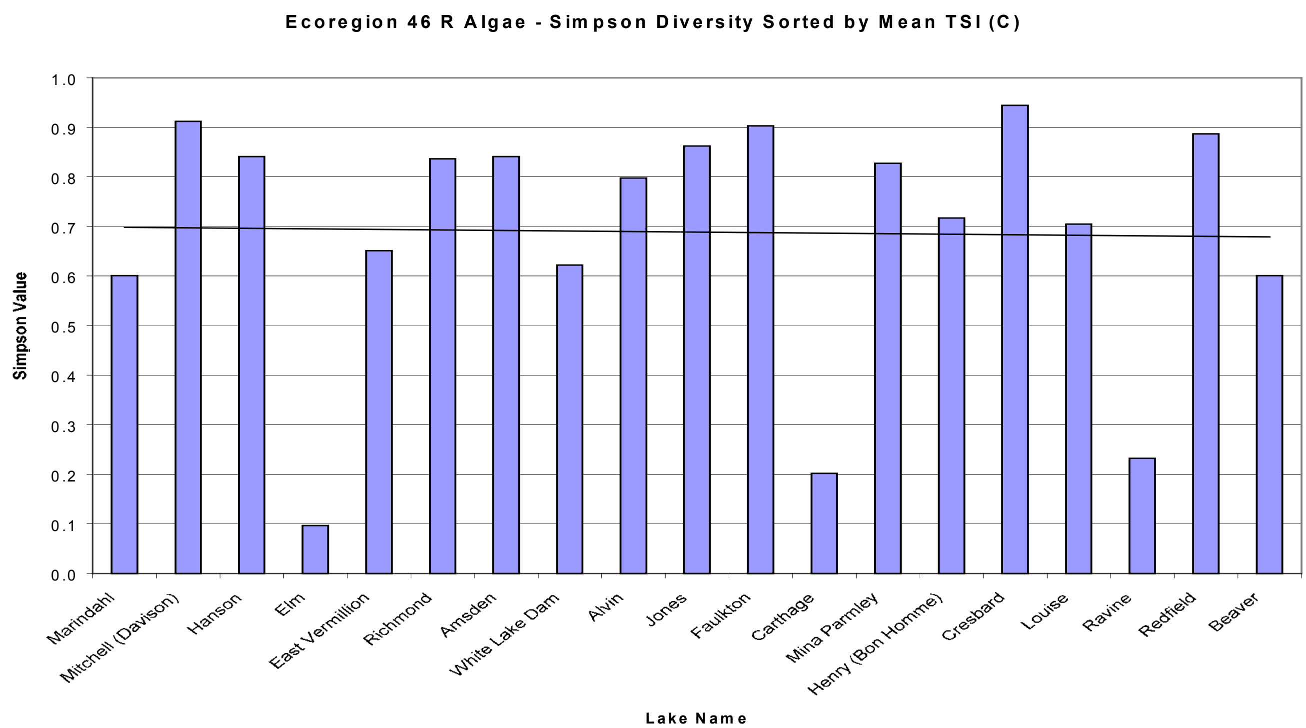

Figure 2.8R. Ecoregion 46R Algae – Simpson diversity sorted by mean TSI (C).

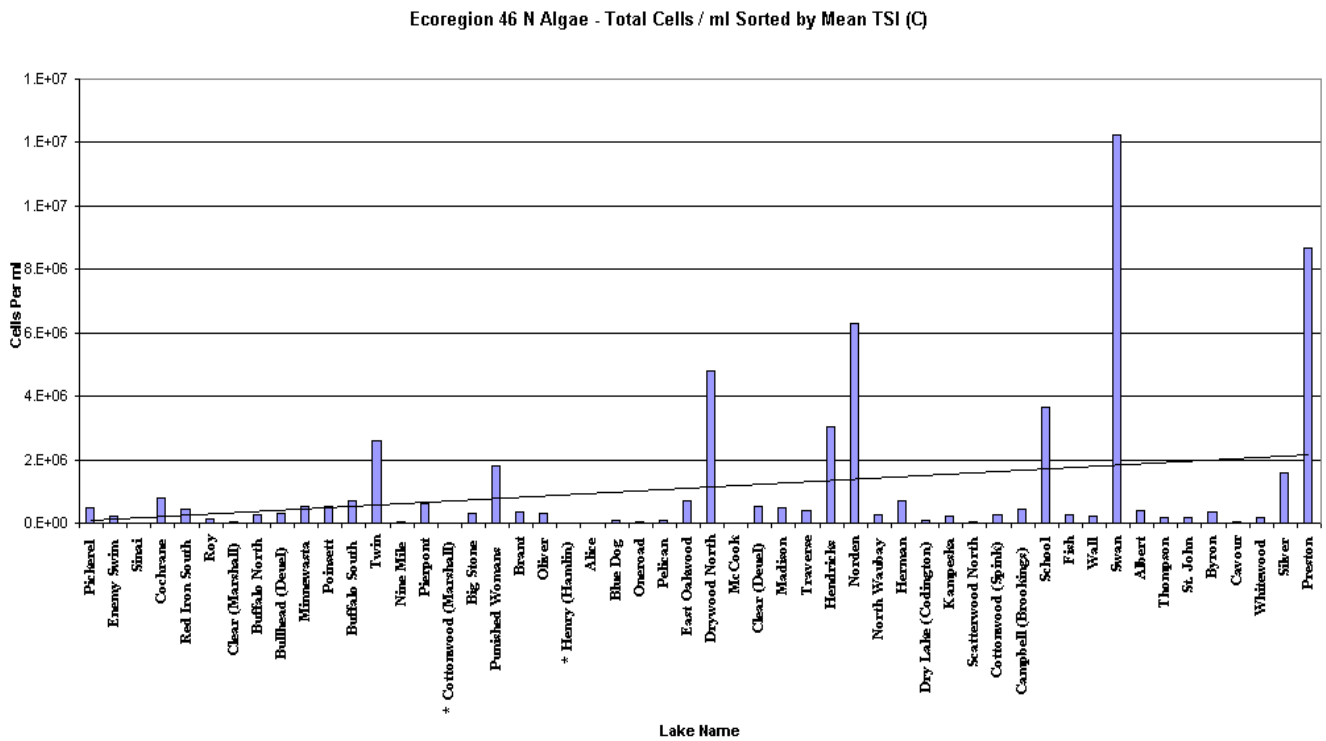

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Figure 2.9N. Ecoregion 46N Algae – Total cells/ml sorted by mean TSI (C).

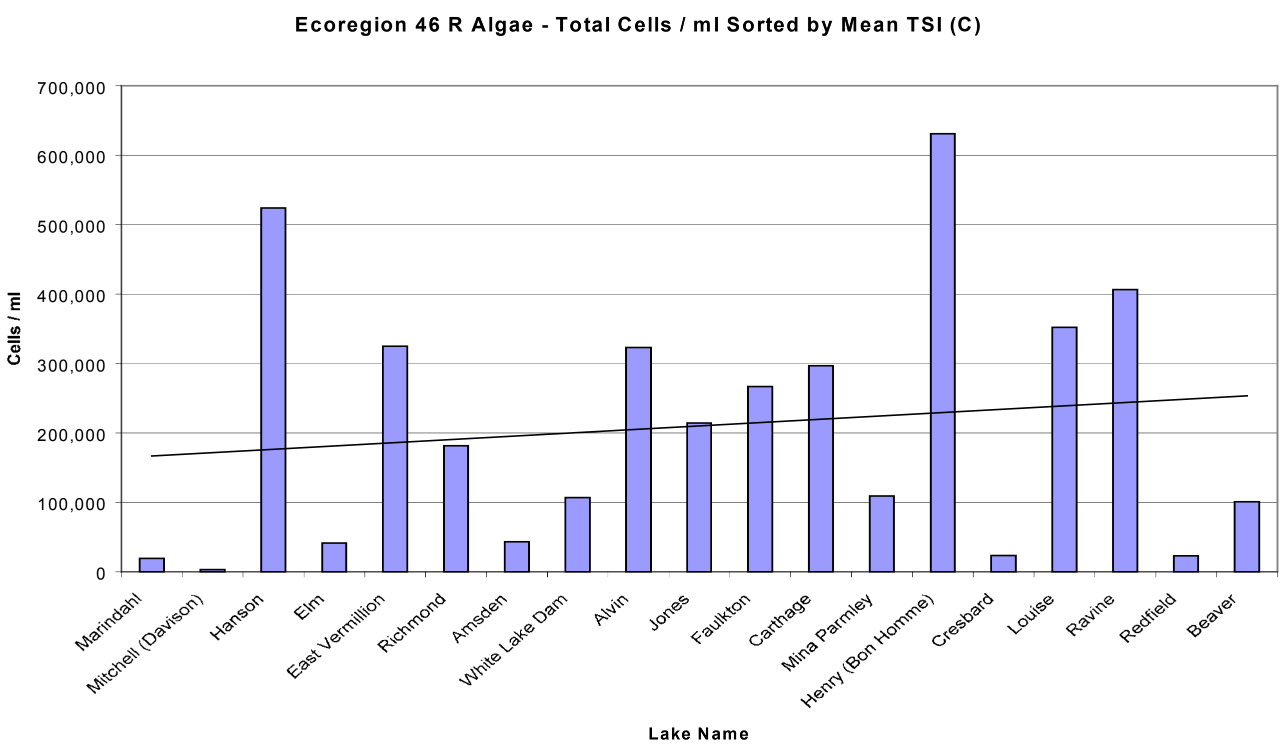

Figure 2.9R. Ecoregion 46R Algae – Total cells/ml sorted by mean TSI (C).

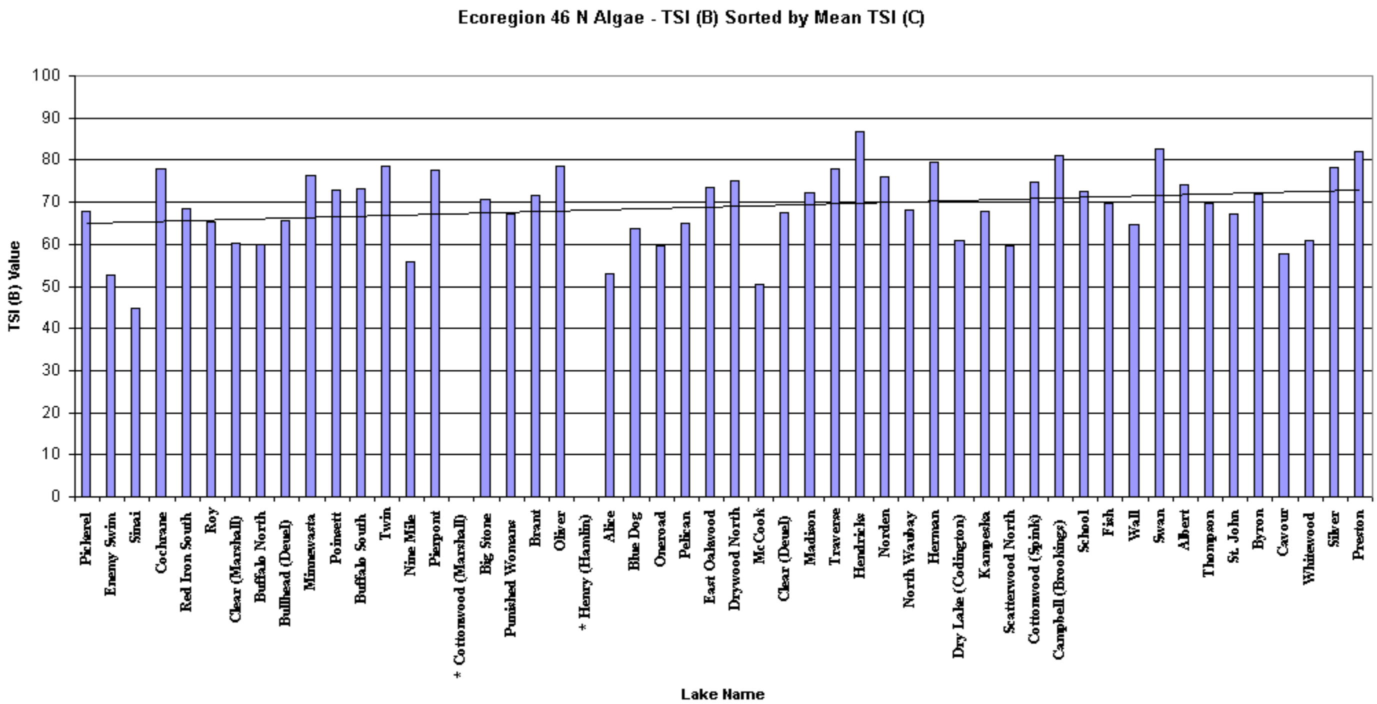

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Figure 2.10N. Ecoregion 46N Algae – TSI (B) (biovolume) sorted by mean TSI (C).

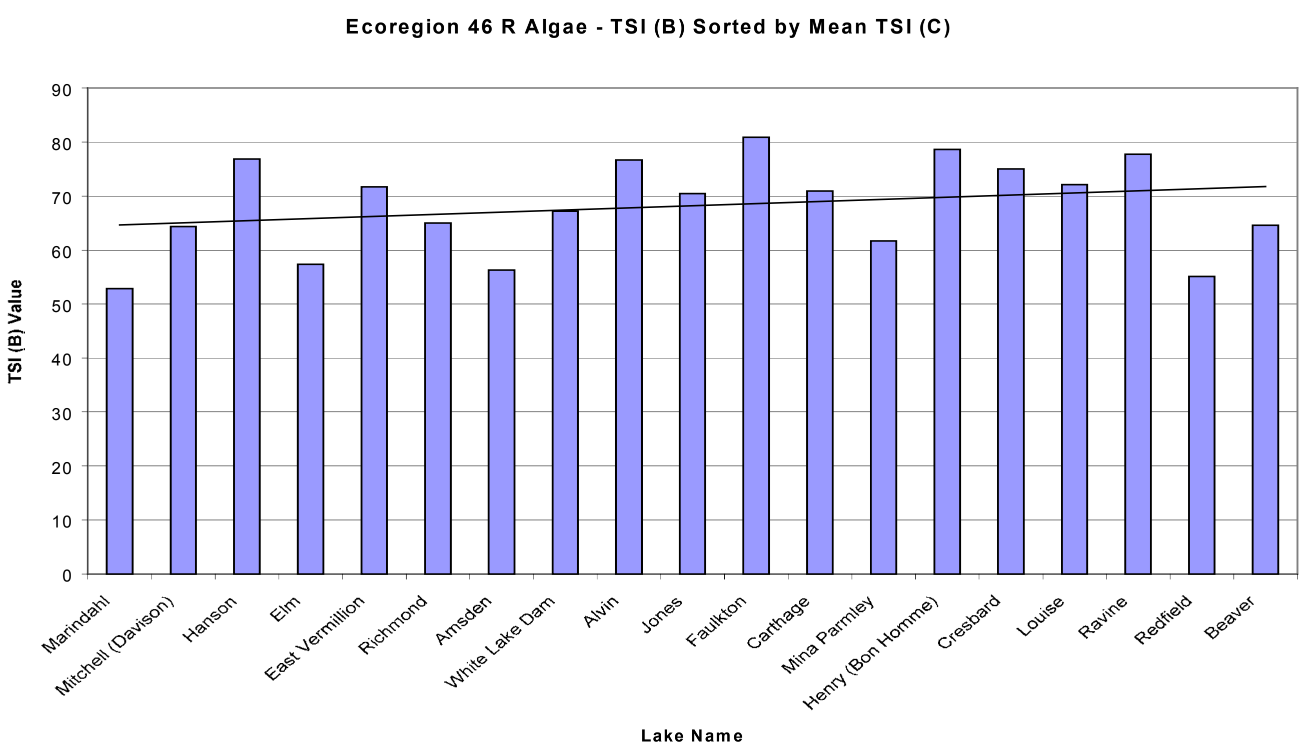

Figure 2.10R. Ecoregion 46R Algae – TSI (biovolume) sorted by mean TSI (C).

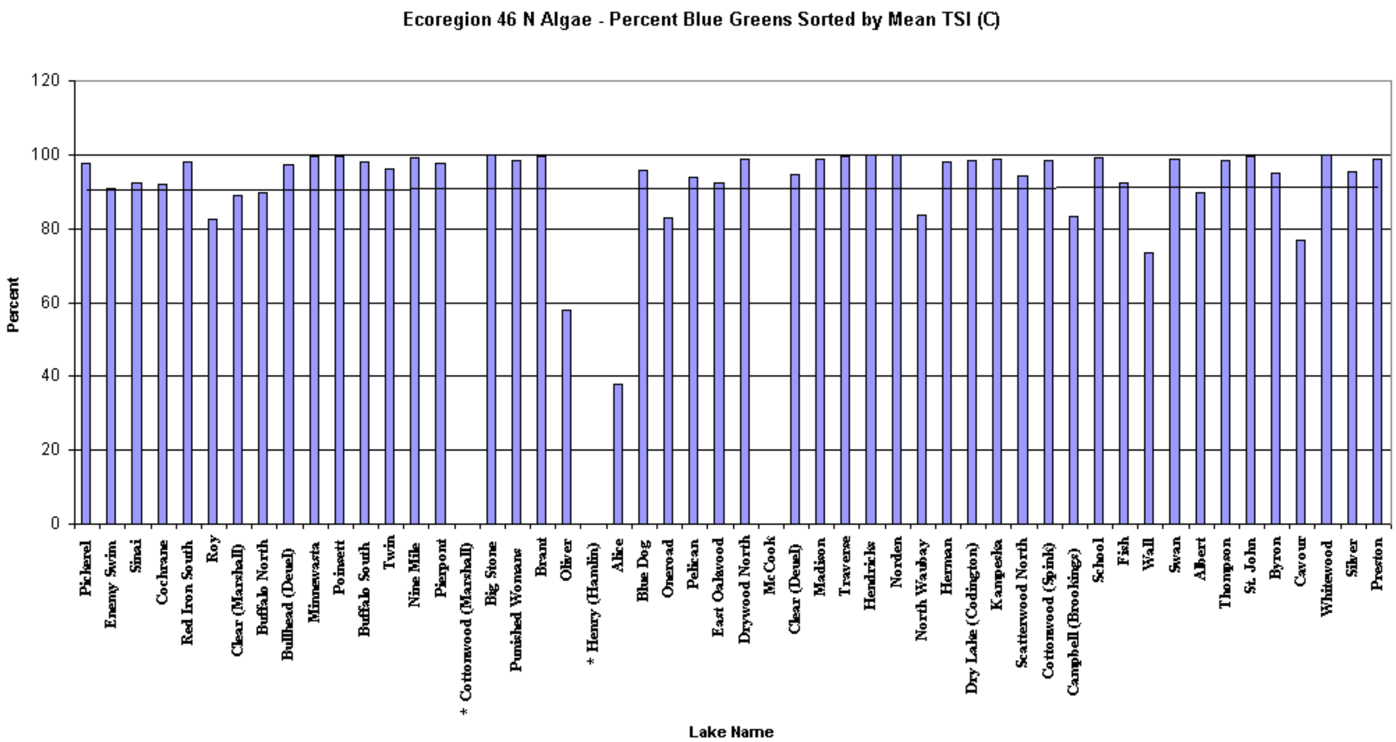

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Figure 2.11N. Ecoregion 46N Algae – Percent blue green algae sorted by mean TSI (C).

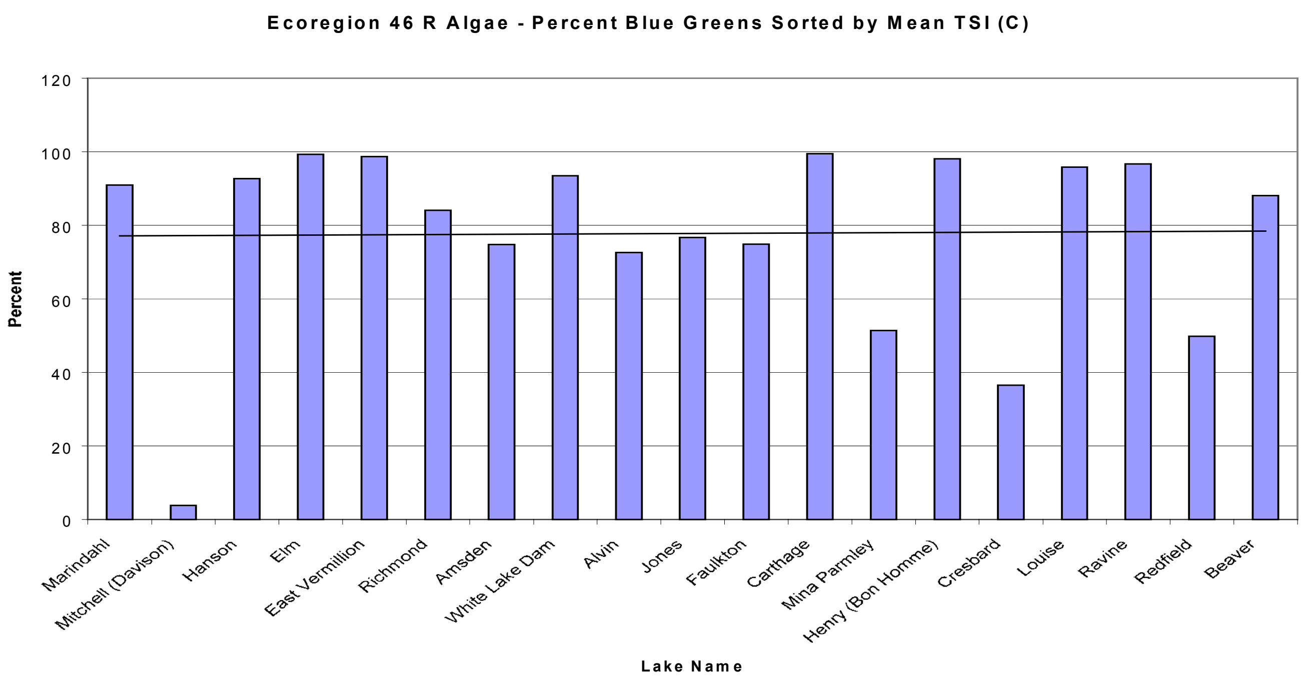

Figure 2.11R. Ecoregion 46R Algae – Percent blue green algae sorted by mean TSI (C).

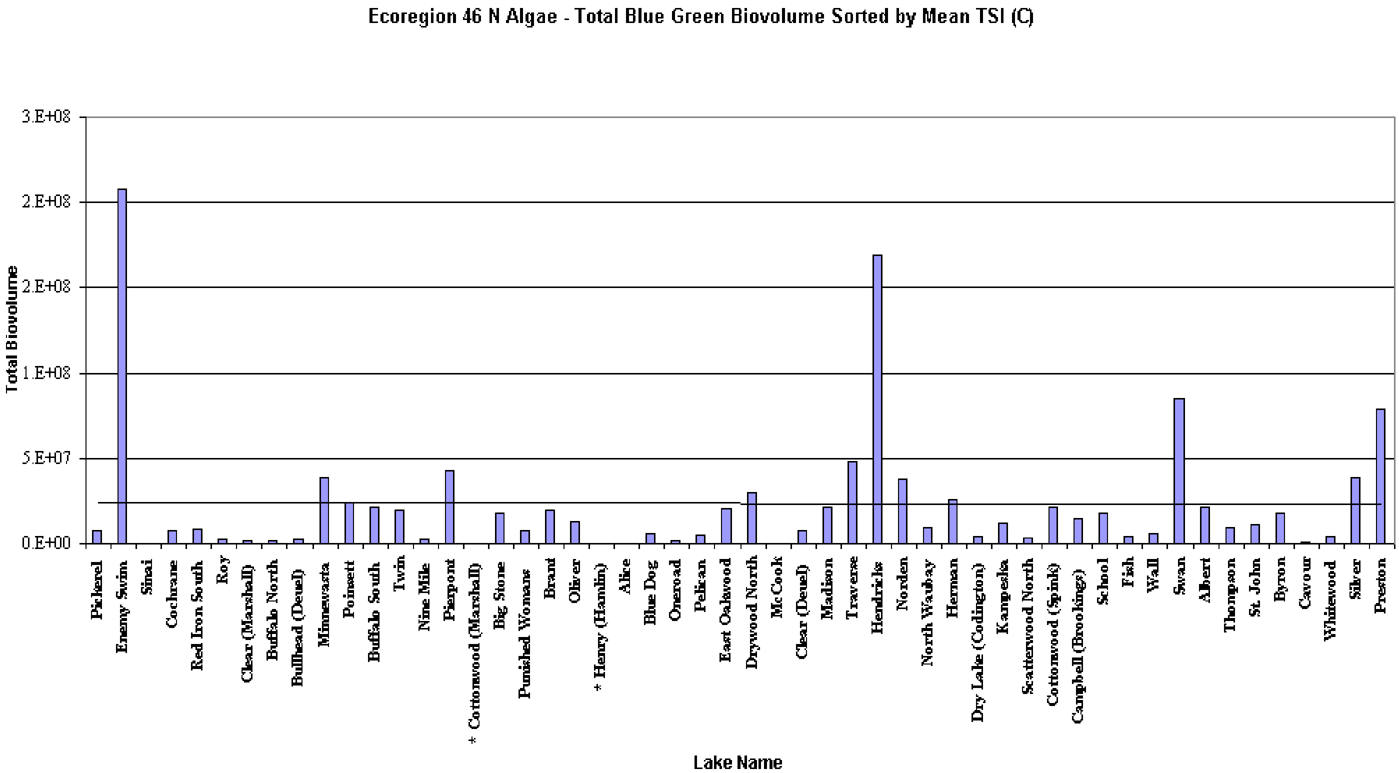

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Figure 2.12N. Ecoregion 46N Algae – Total blue green biovolume sorted by mean TSI (C).

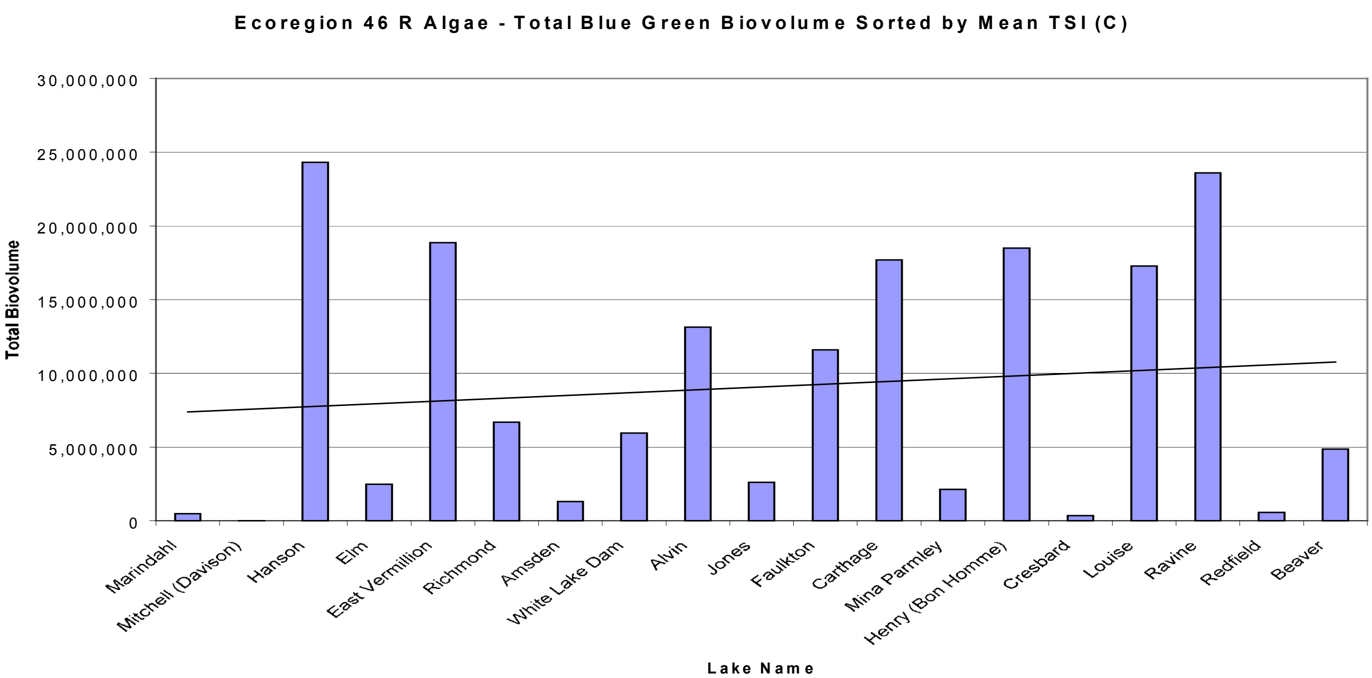

Figure 2.12R. Ecoregion 46R Algae – Total blue green biovolume sorted by mean TSI (C).

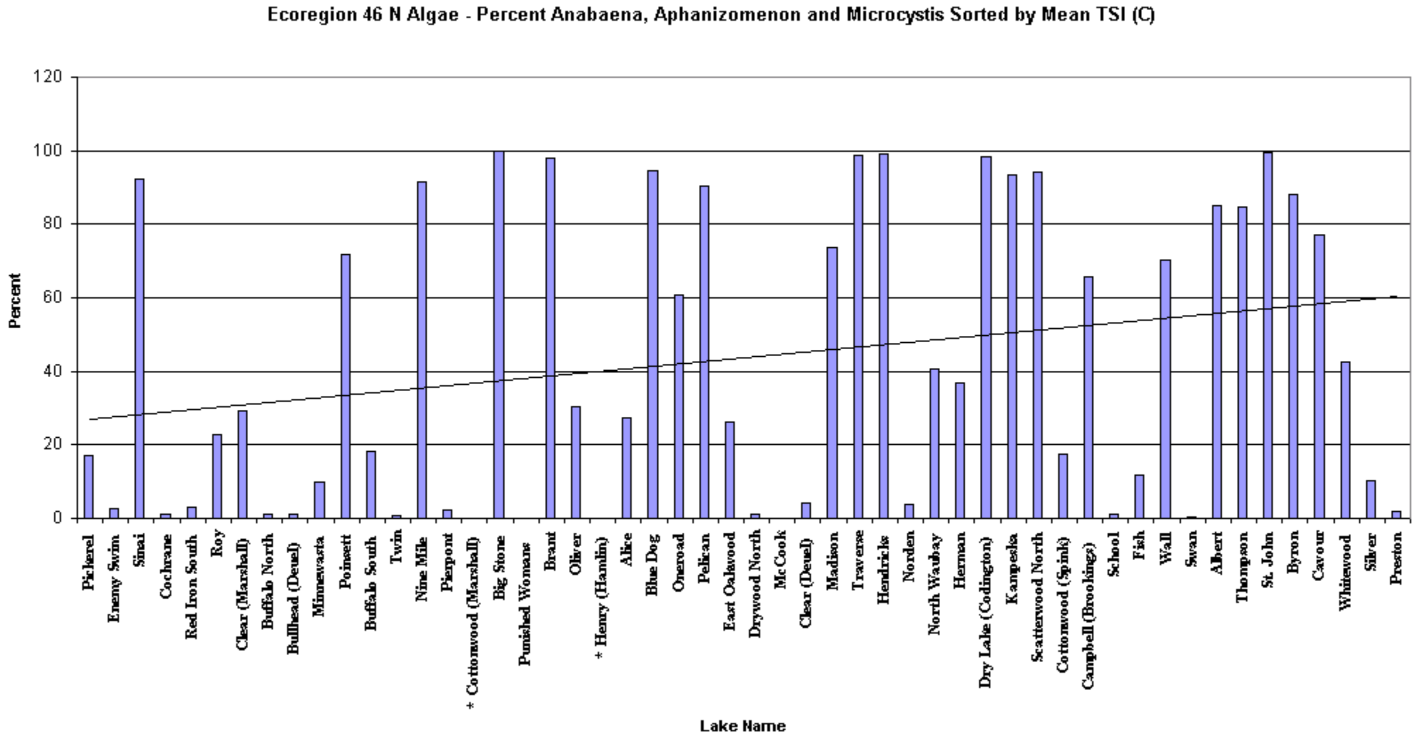

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Figure 2.13N. Ecoregion 46N Algae – Percent Anabaena, Aphanizomenon and Microcystis sorted by mean TSI (C).

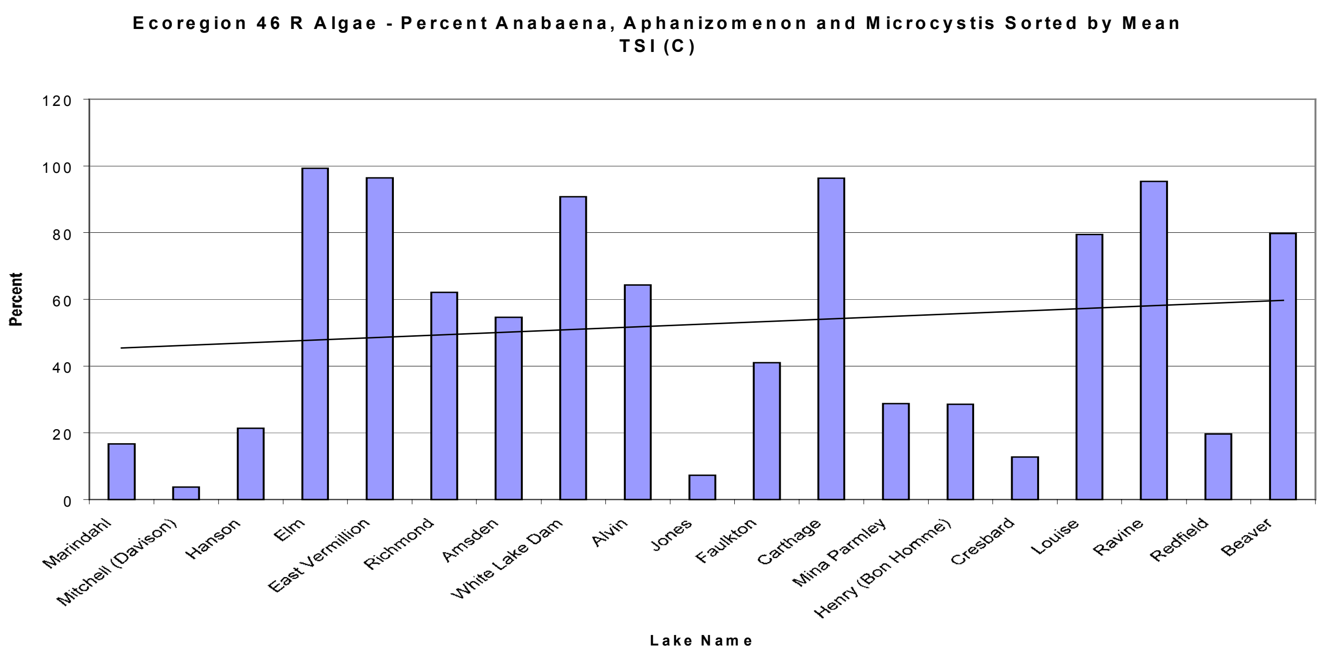

Figure 2.13R. Ecoregion 46R Algae – Percent Anabaena, Aphanizomenon and Microcystis sorted by mean TSI (C).

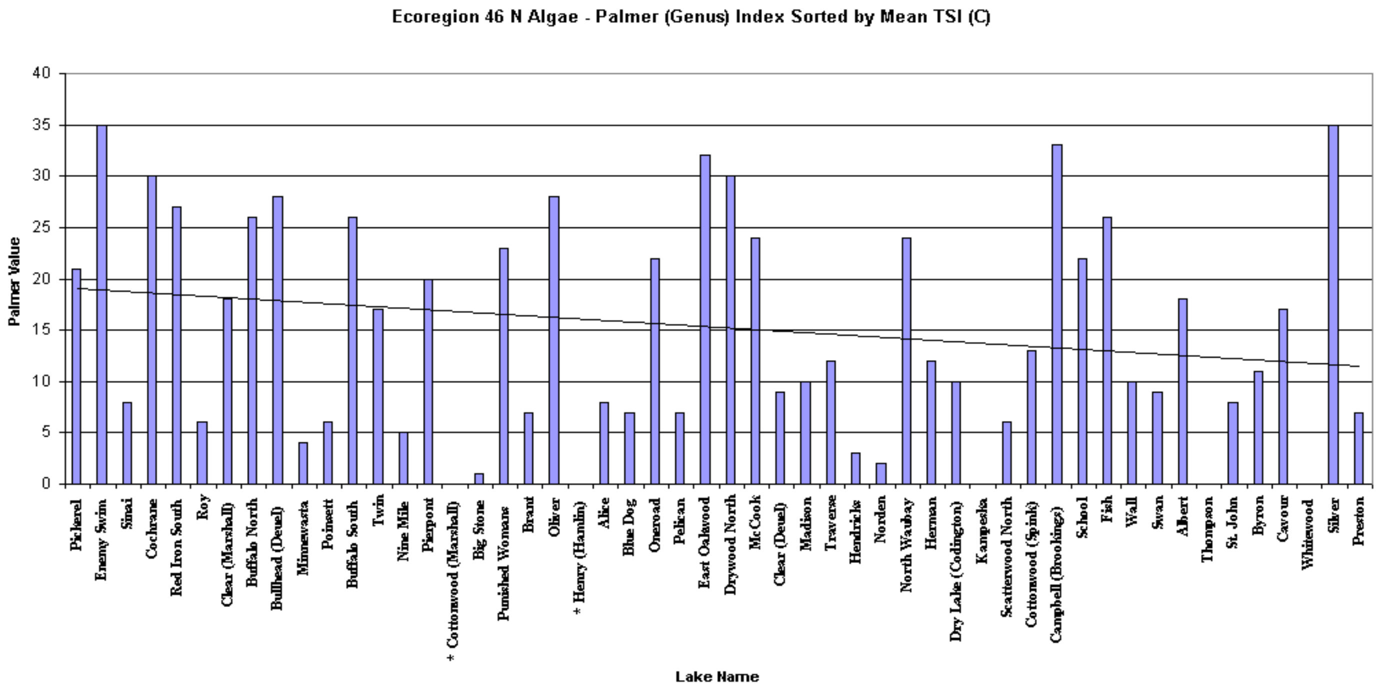

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Figure 2.14N. Ecoregion 46N Algae – Palmer index (Genus) sorted by mean TSI (C).

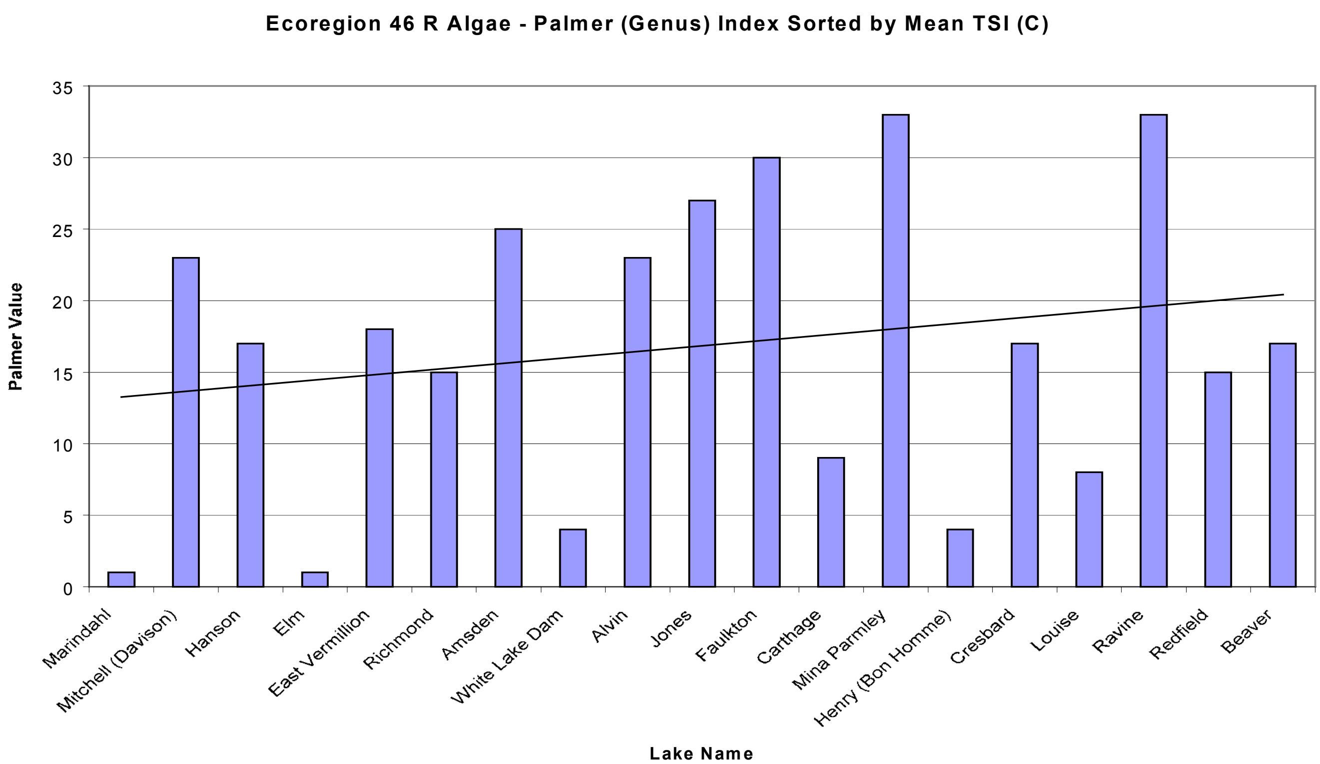

Figure 2.14R. Ecoregion 46R Algae – Palmer index (Genus) sorted by mean TSI (C).

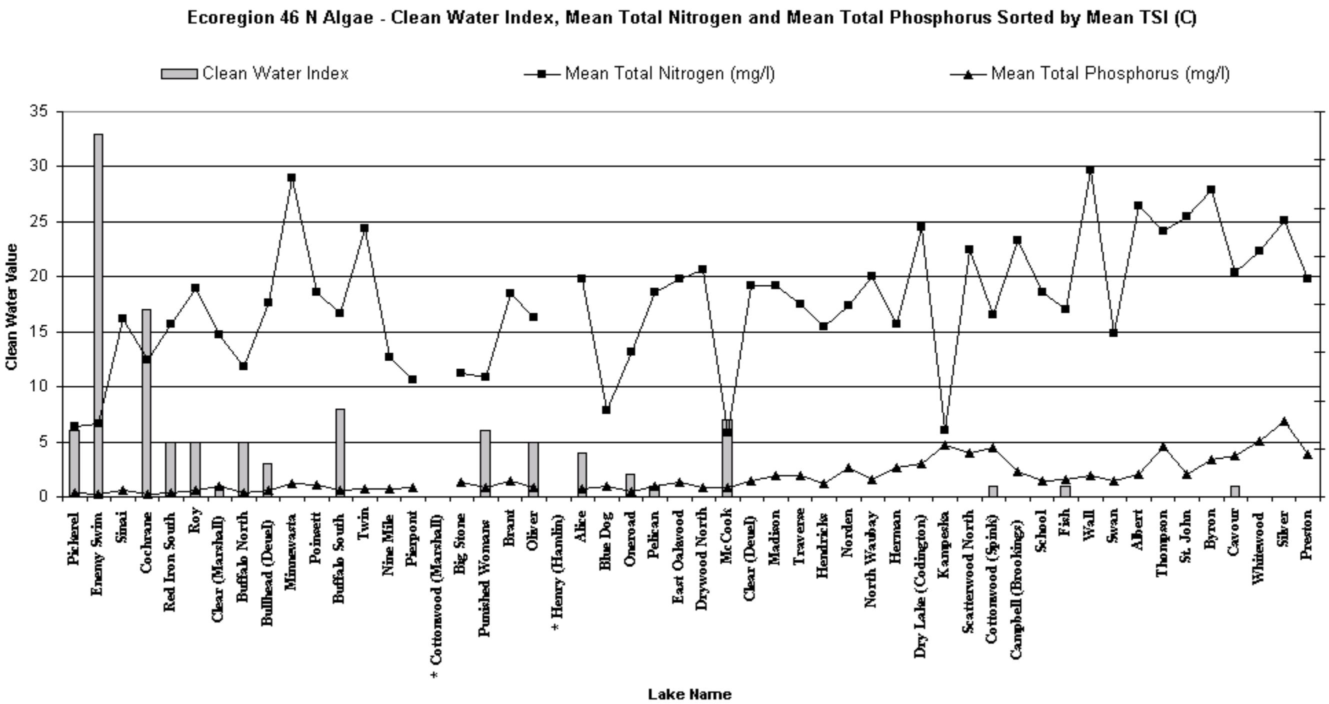

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Figure 2.15N. Ecoregion 46N Algae – Clean water index, mean total nitrogen, and mean total phosphorus sorted by mean TSI (C).

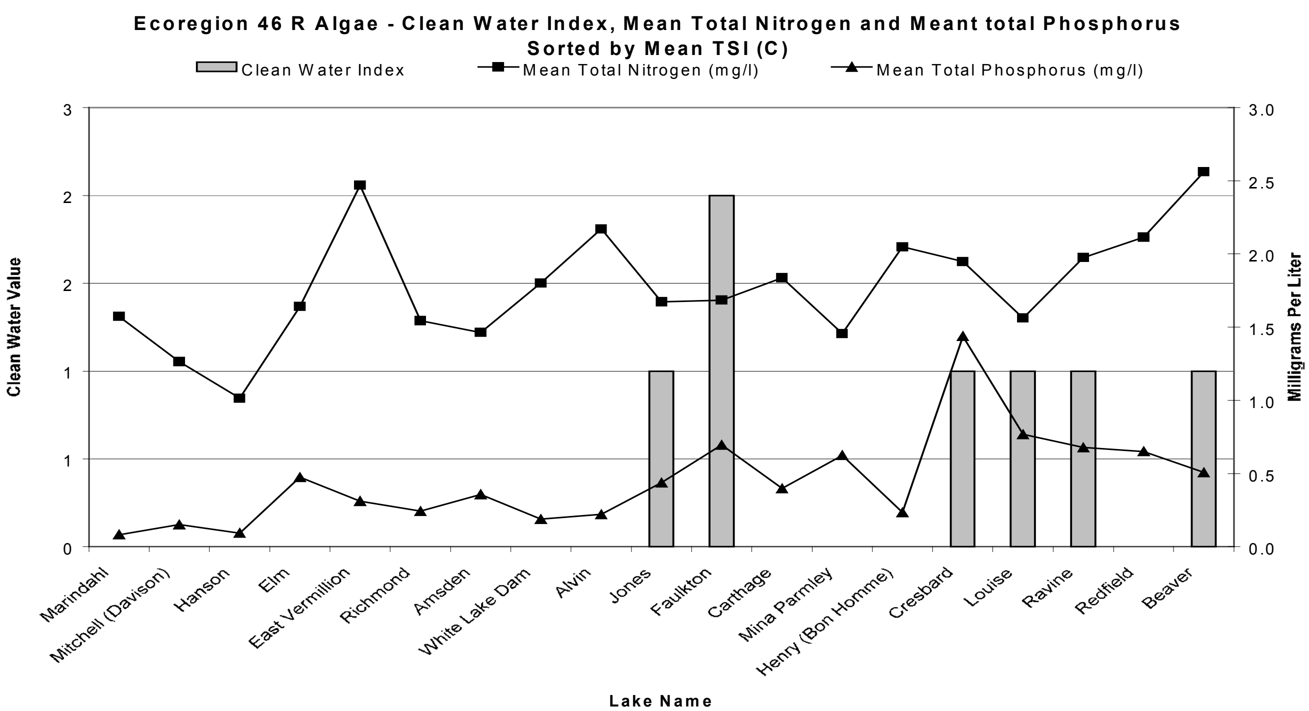

Figure 2.15R. Ecoregion 46R Algae – Clean water index, mean total nitrogen, and mean total phosphorus sorted by mean TSI (C).

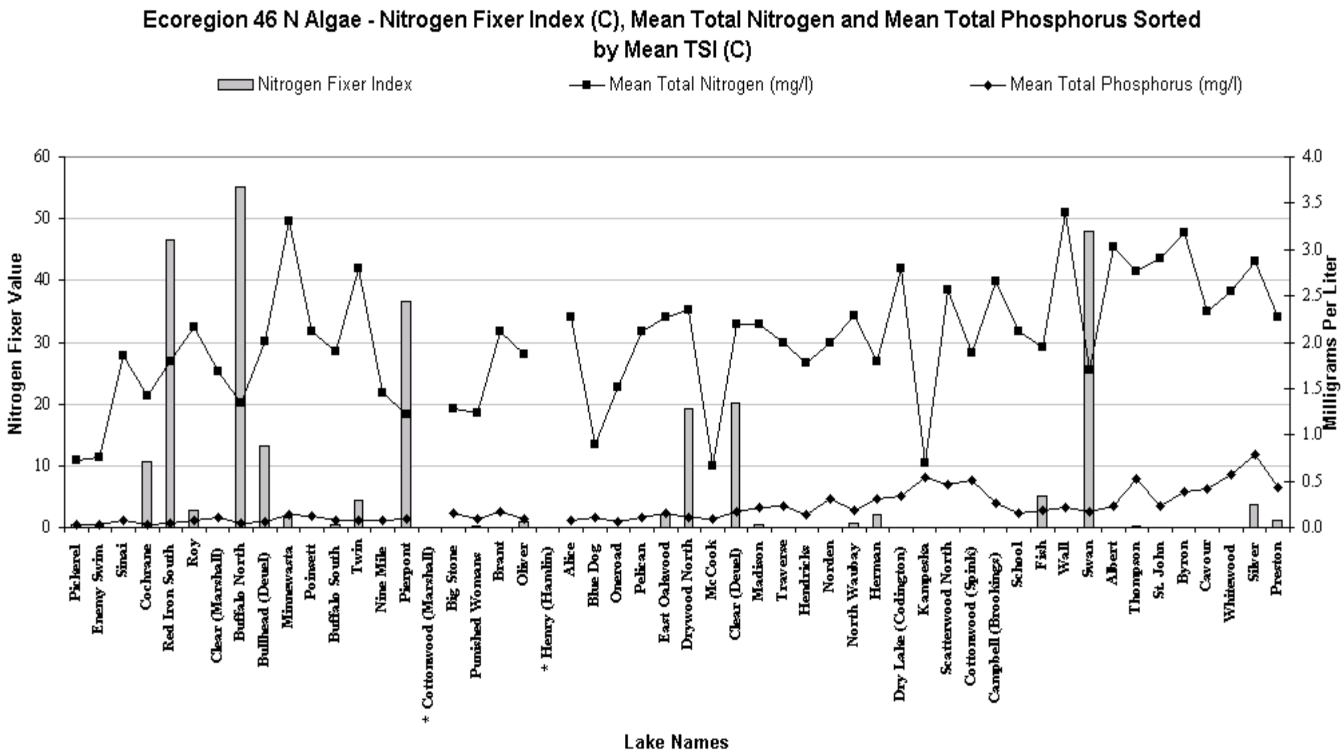

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Figure 2.16N. Ecoregion 46N Algae – Nitrogen fixer index (cells/ml), mean total nitrogen, and mean total phosphorus sorted by mean TSI (C).

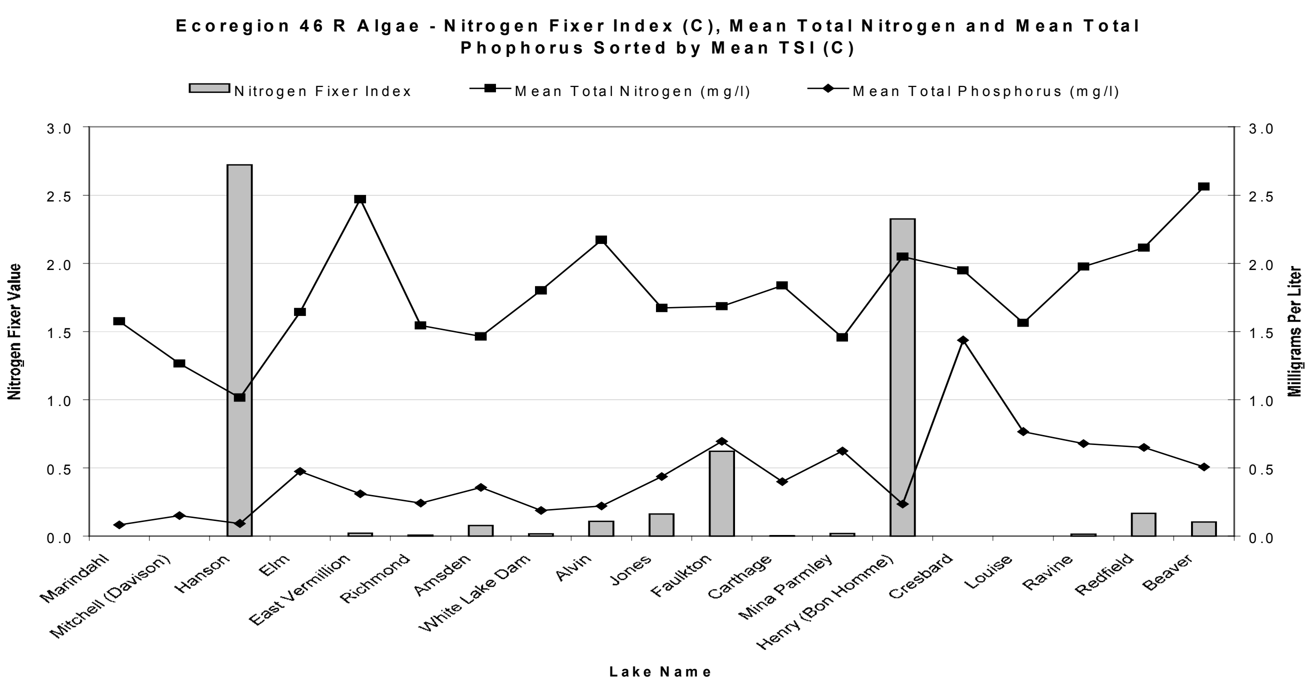

Figure 2.16R. Ecoregion 46R Algae – Nitrogen fixer index (cells/ml), mean total nitrogen, and mean total phosphorus sorted by mean TSI (C).

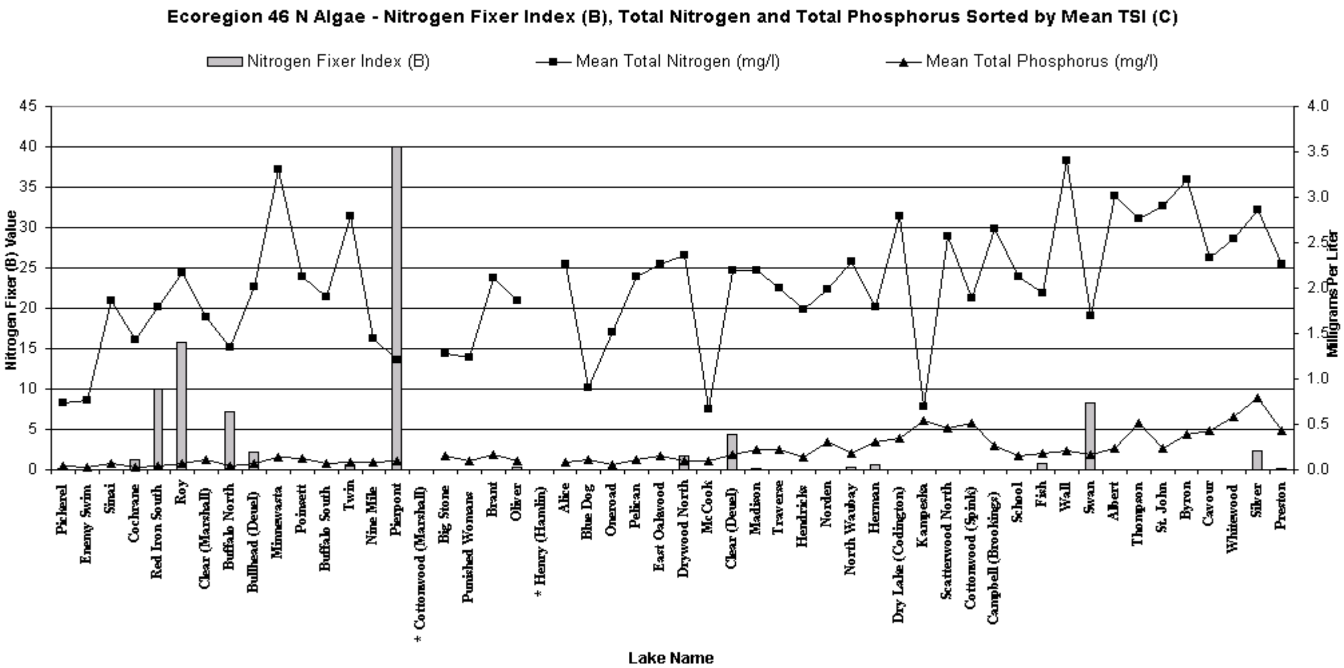

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Figure 2.17N. Ecoregion 46N Algae – Nitrogen fixer index (biovolume), mean total nitrogen, and mean total phosphorus sorted by mean TSI (C).

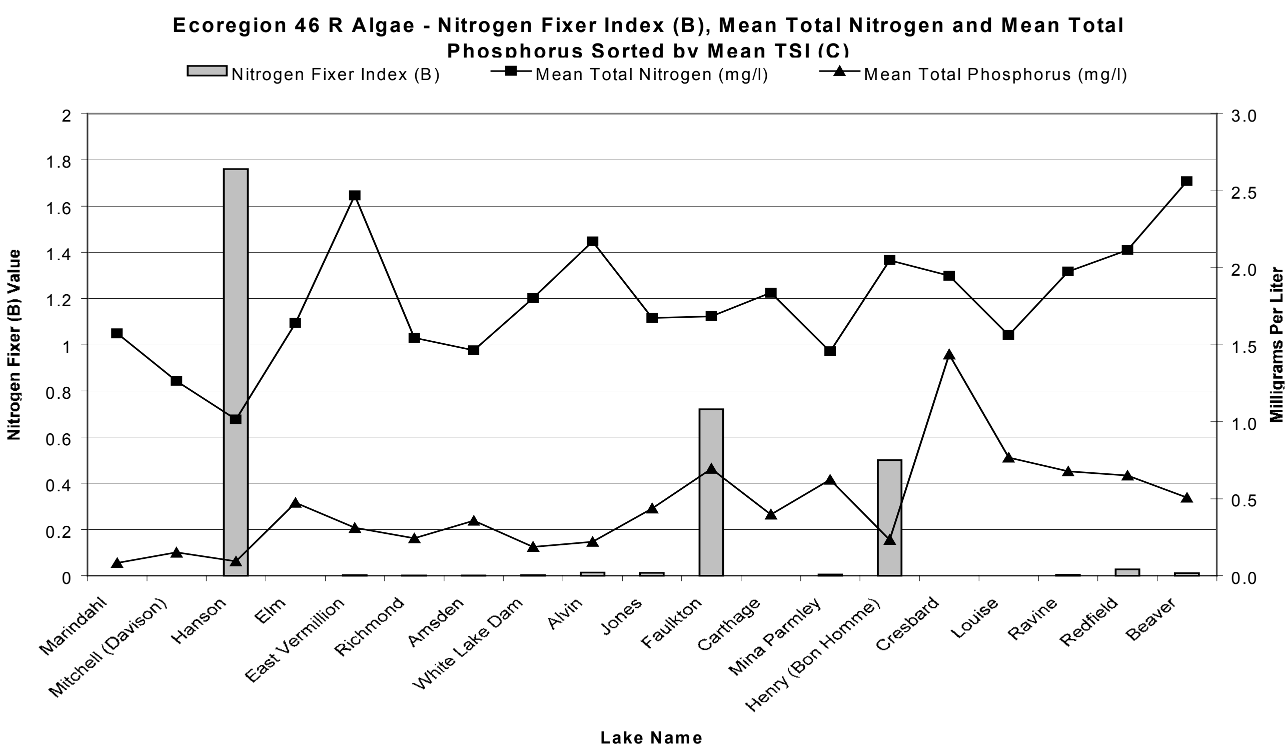
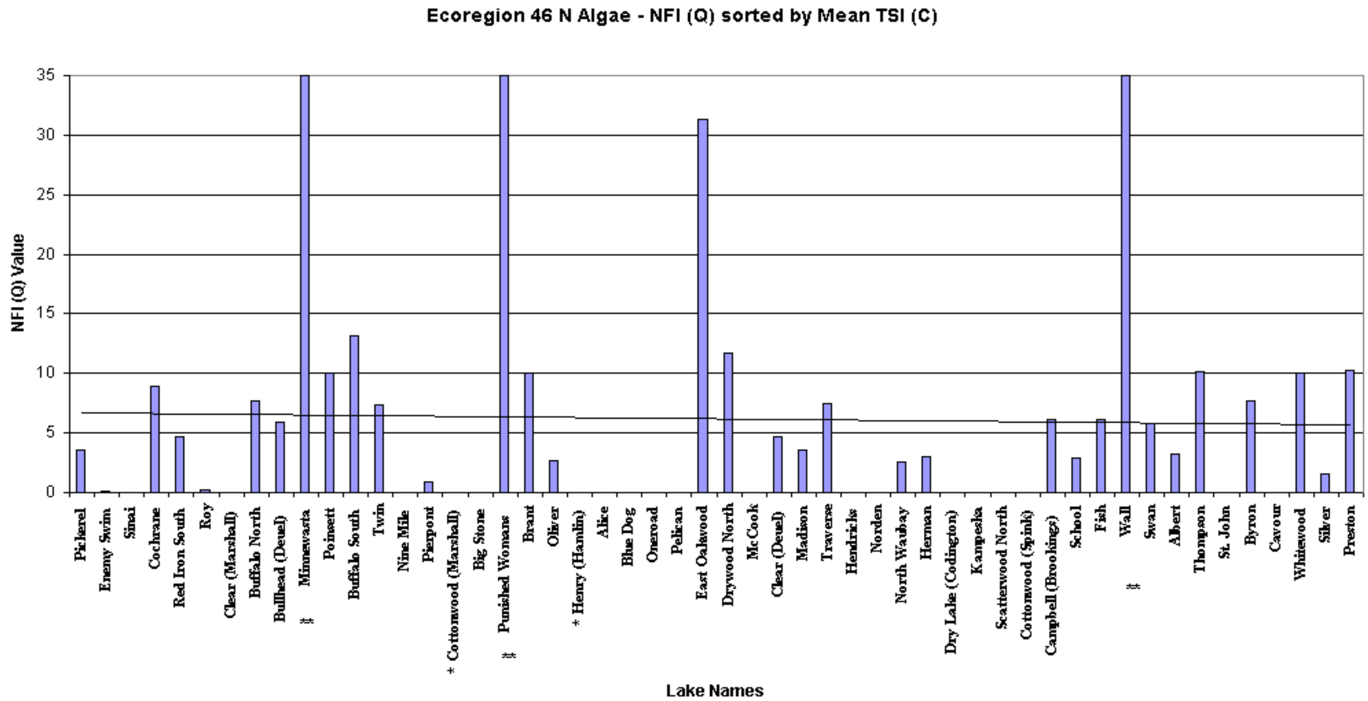


Figure 2.17R. Ecoregion 46R Algae – Nitrogen fixer index (biovolume), mean total nitrogen, and mean total phosphorus sorted by mean TSI (C).



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** NFI (Q) values exceeded 35 units

Figure 2.18N. Ecoregion 46N Algae – Nitrogen fixer index (quotient) sorted by mean TSI (C).

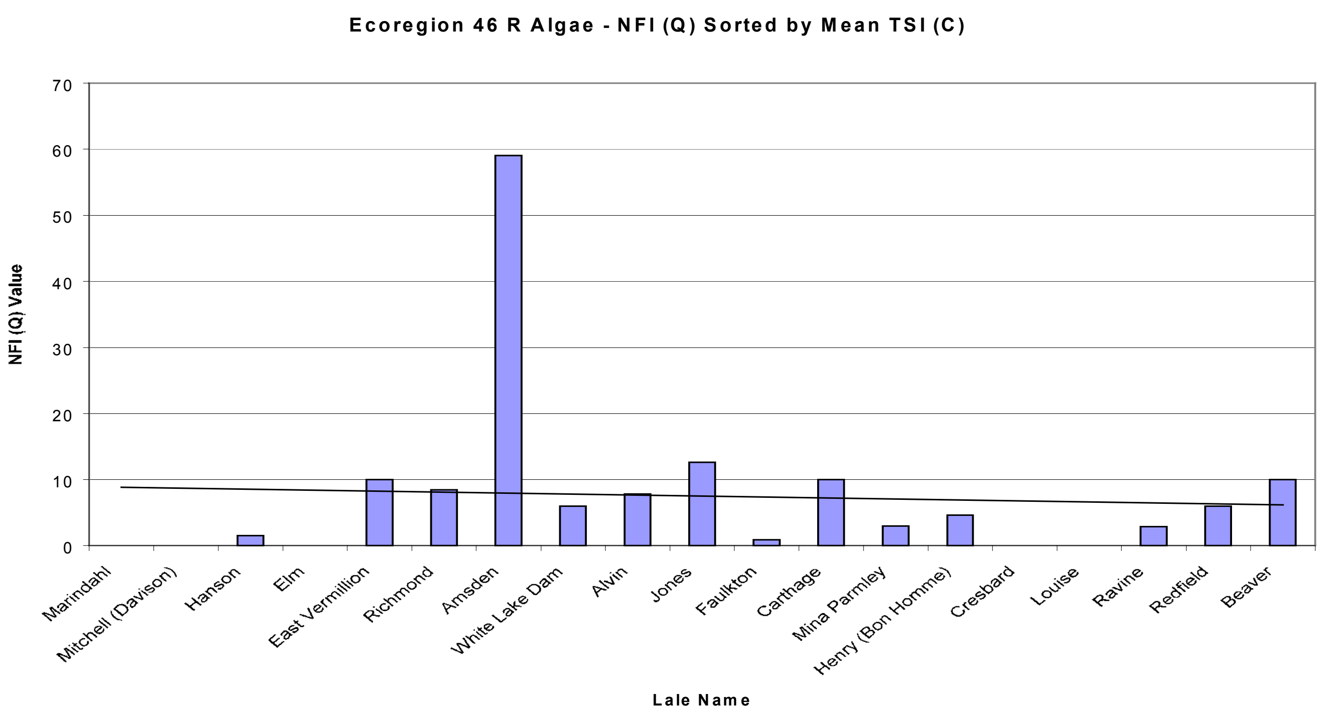

Figure 2.18R. Ecoregion 46R Algae – Nitrogen fixer index (quotient) sorted by mean TSI (C).

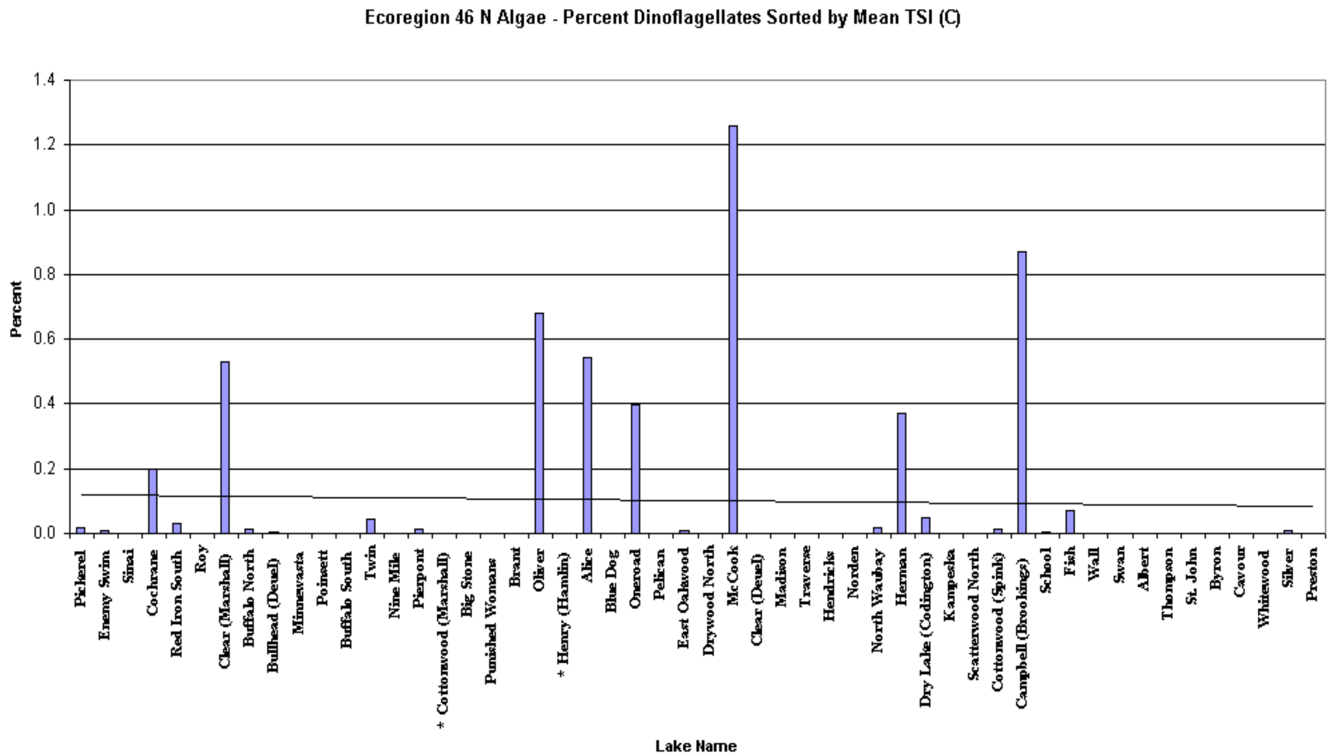

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Figure 2.19N. Ecoregion 46N Algae – Percent dinoflagellates sorted by mean TSI (C).

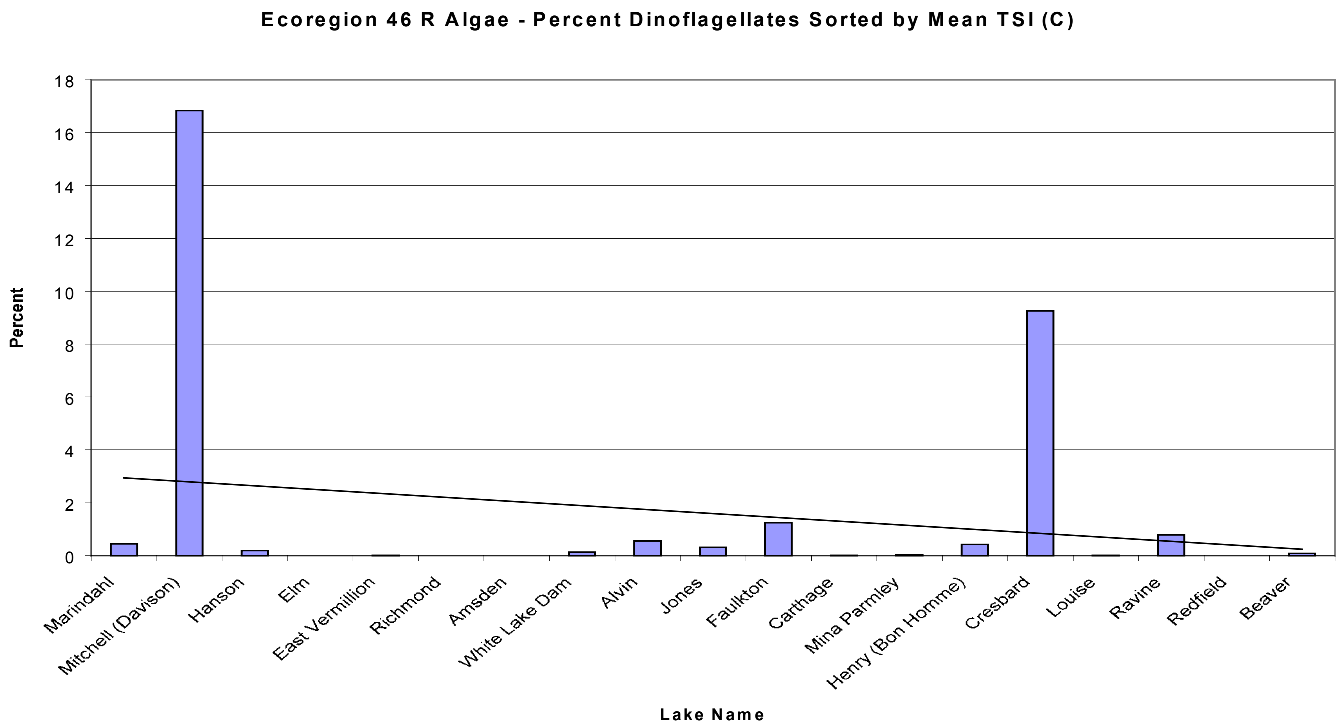

Figure 2.19R. Ecoregion 46R Algae – Percent dinoflagellates sorted by mean TSI (C).

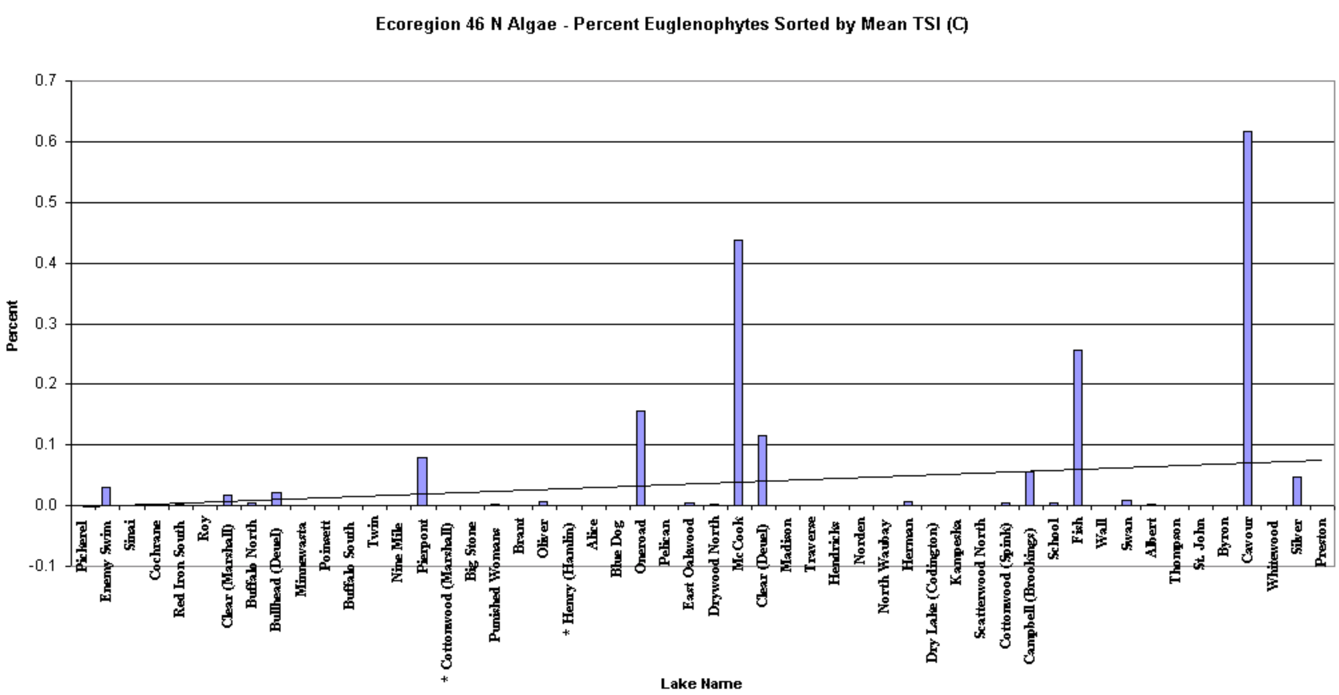

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Figure 2.20N. Ecoregion 46N Algae – Percent euglenophytes sorted by mean TSI (C).

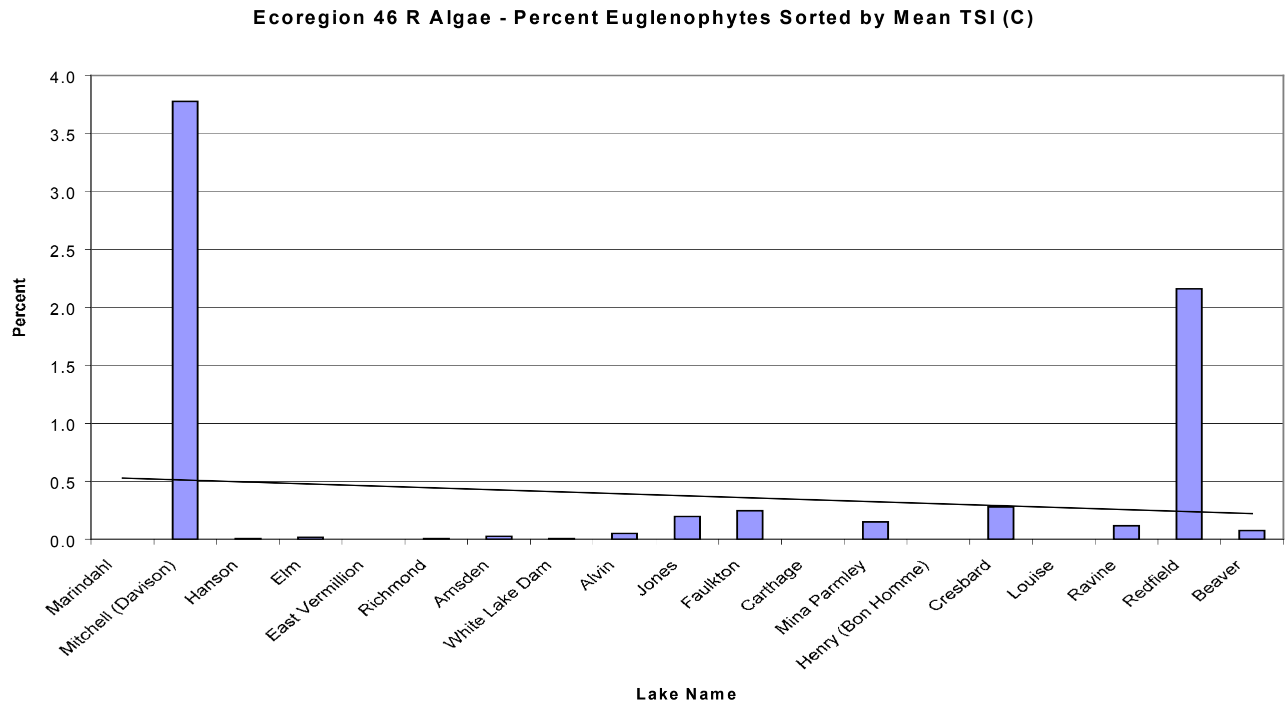

Figure 2.20R. Ecoregion 46R Algae – Percent euglenophytes sorted by mean TSI (C).

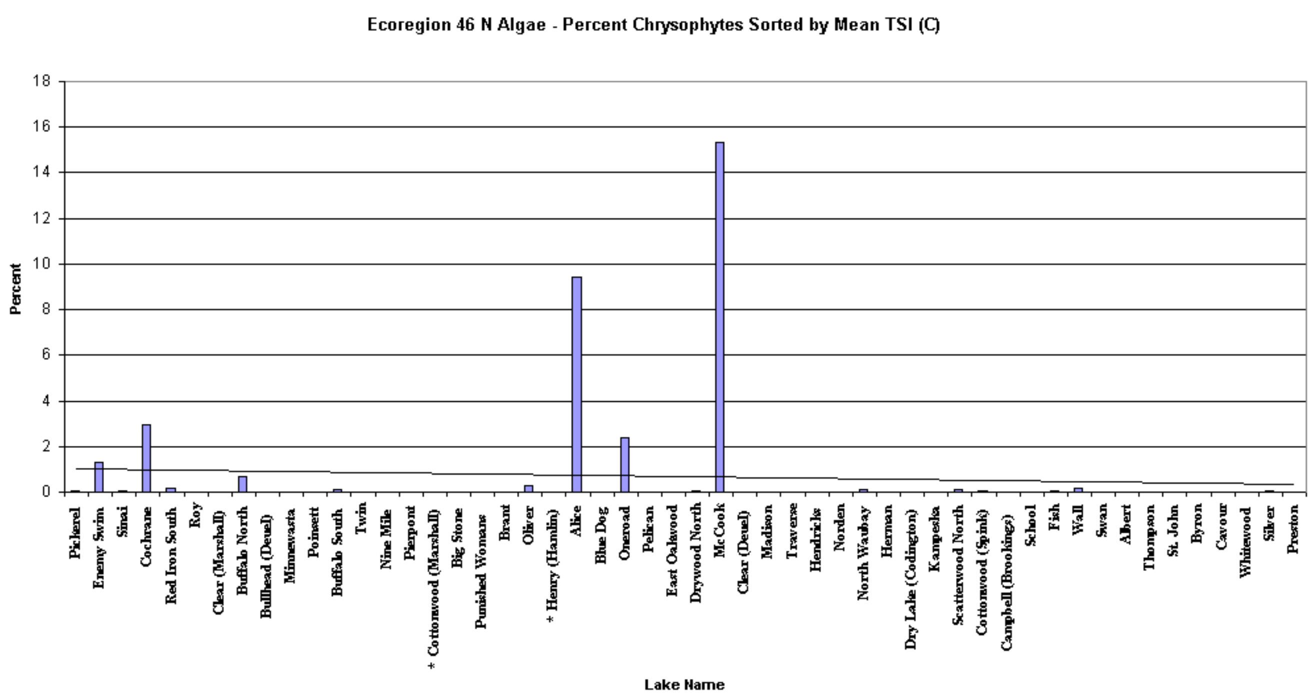

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Figure 2.21N. Ecoregion 46N Algae – Percent chrysophytes sorted by mean TSI (C).

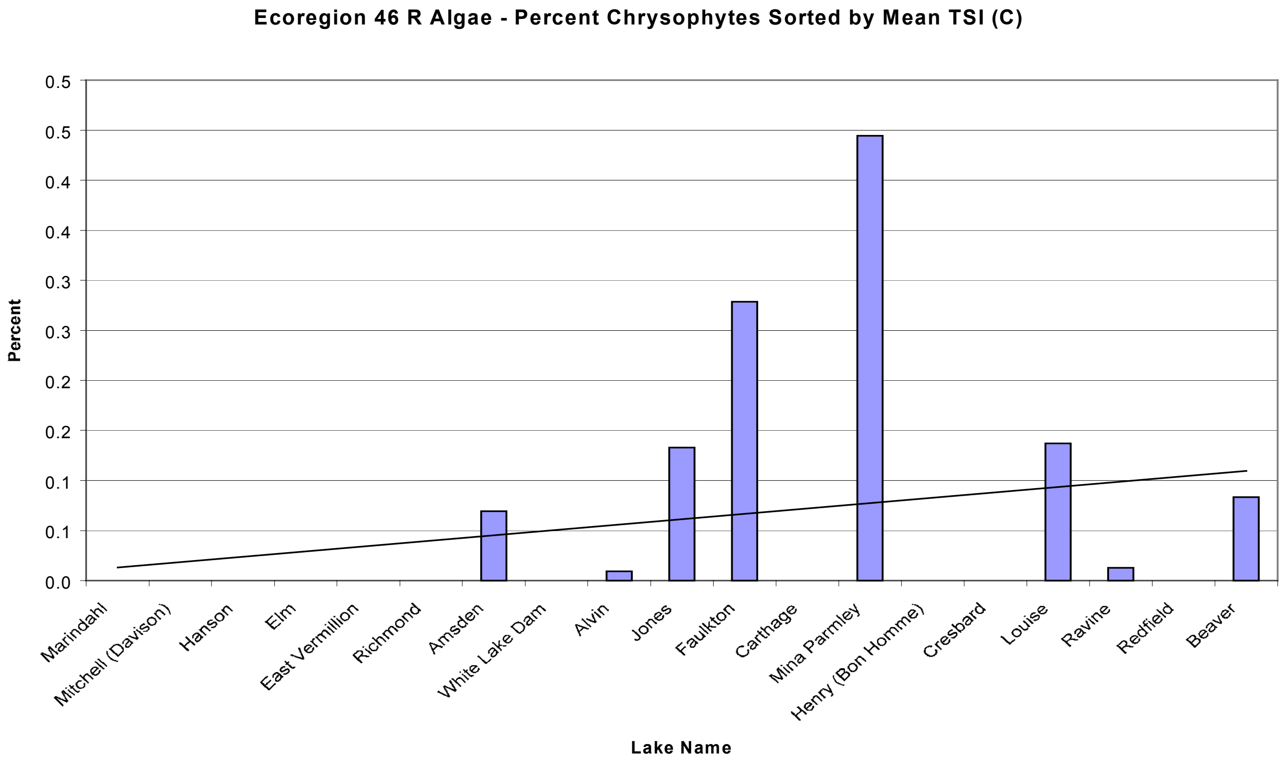

Figure 2.21R. Ecoregion 46R Algae – Percent chrysophytes sorted by mean TSI (C).

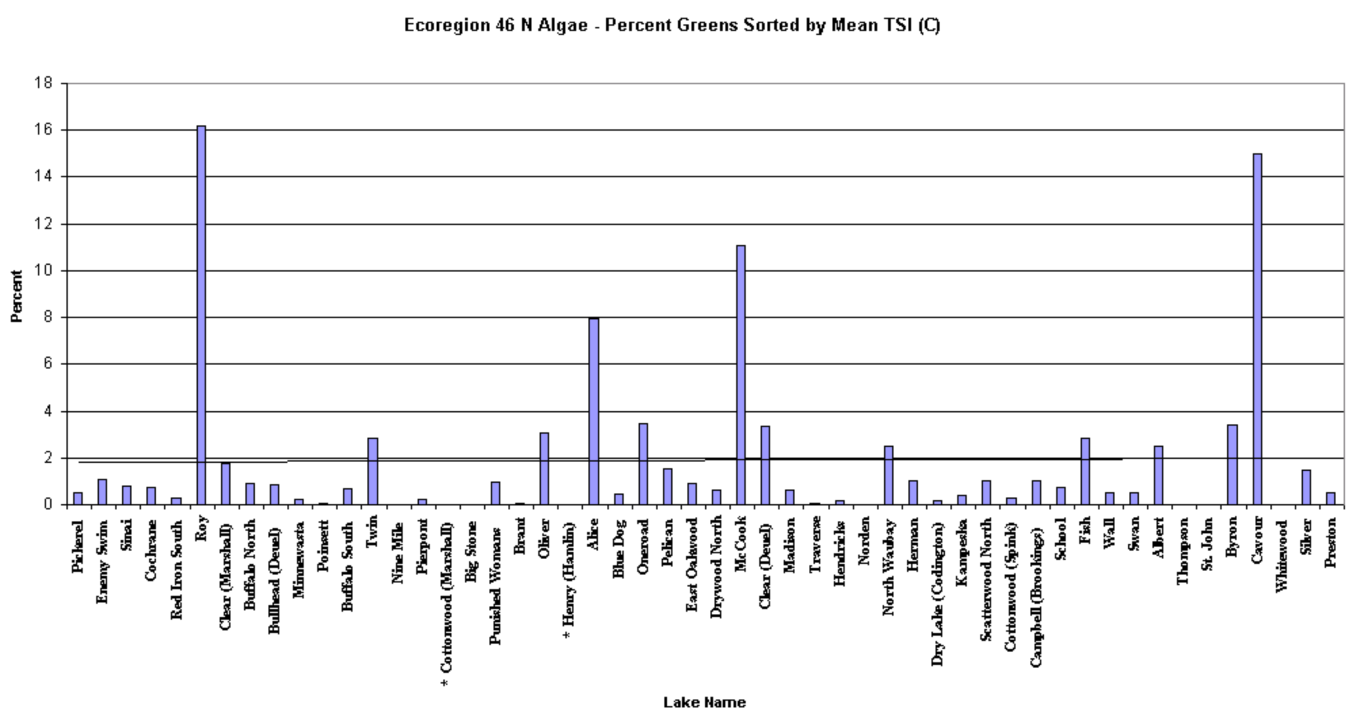

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Figure 2.22N. Ecoregion 46N Algae – Percent green algae sorted by mean TSI (C).

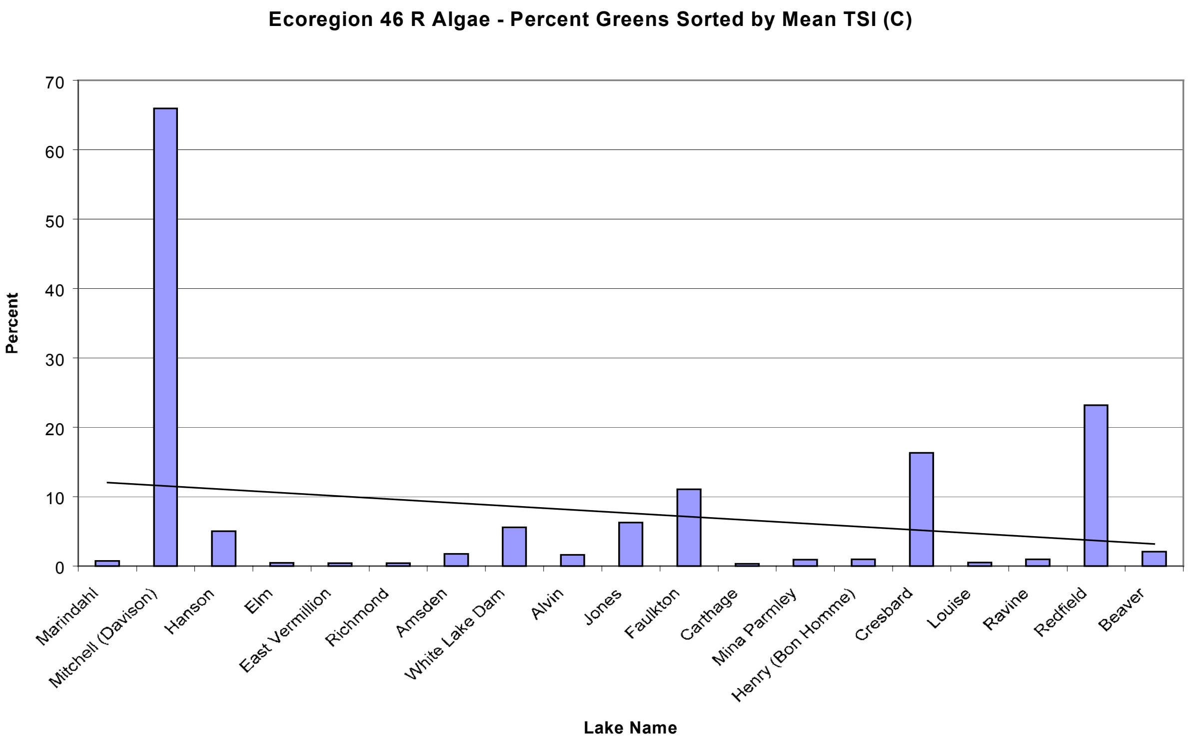

Figure 2.22R. Ecoregion 46R Algae – Percent green algae sorted by mean TSI (C).

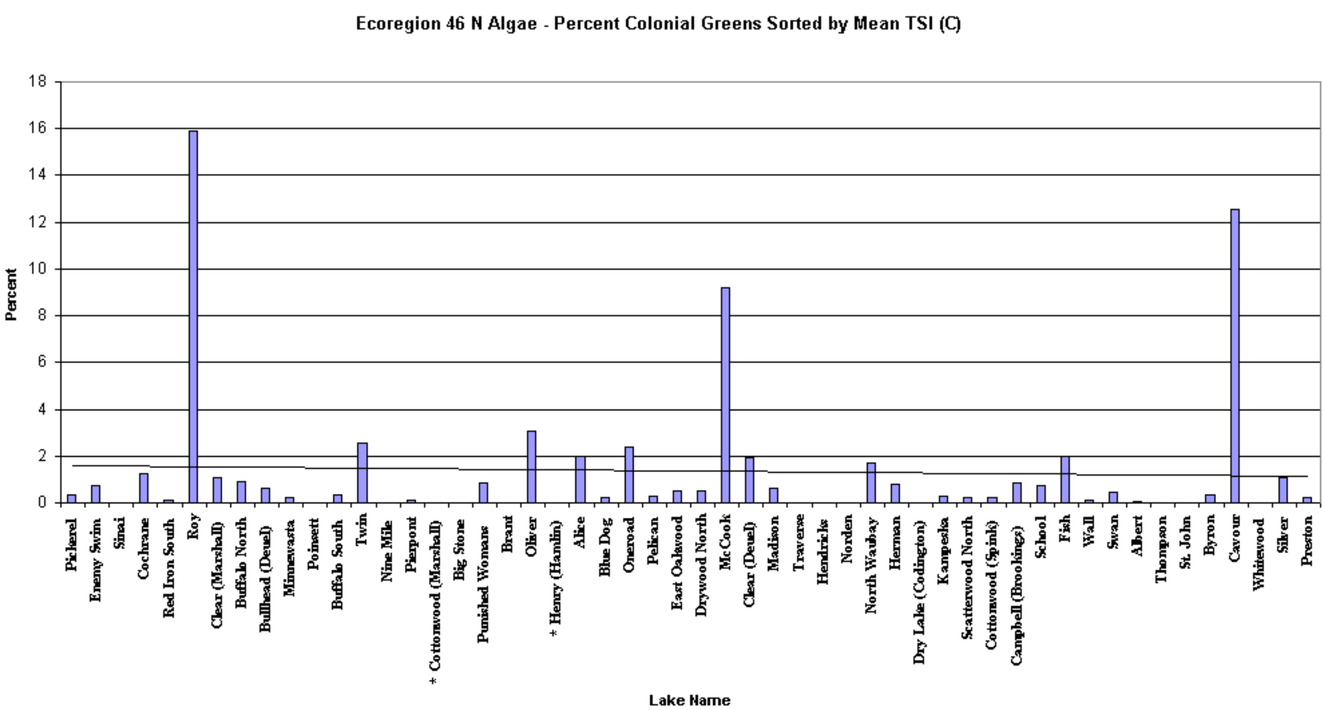

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Figure 2.23N. Ecoregion 46N Algae – Percent colonial green algae sorted by mean TSI (C).

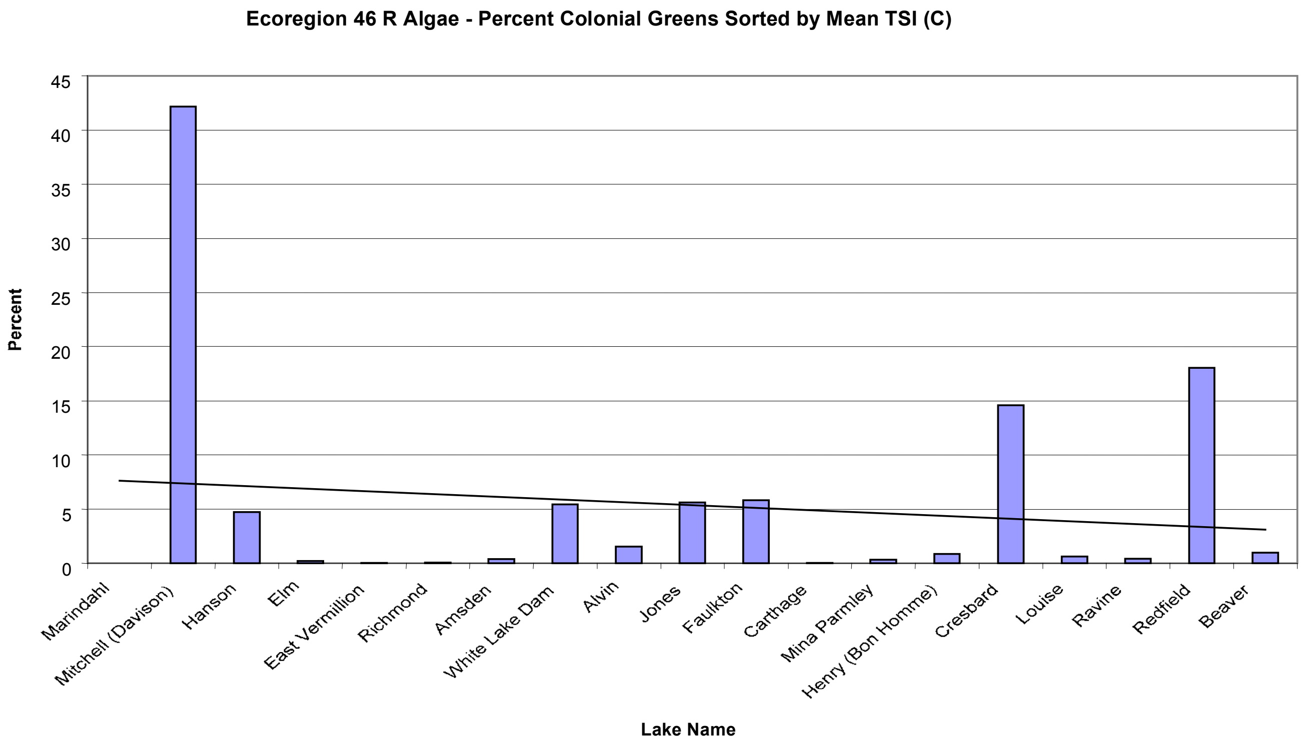

Figure 2.23R. Ecoregion 46R Algae – Percent colonial green algae sorted by mean TSI (C).

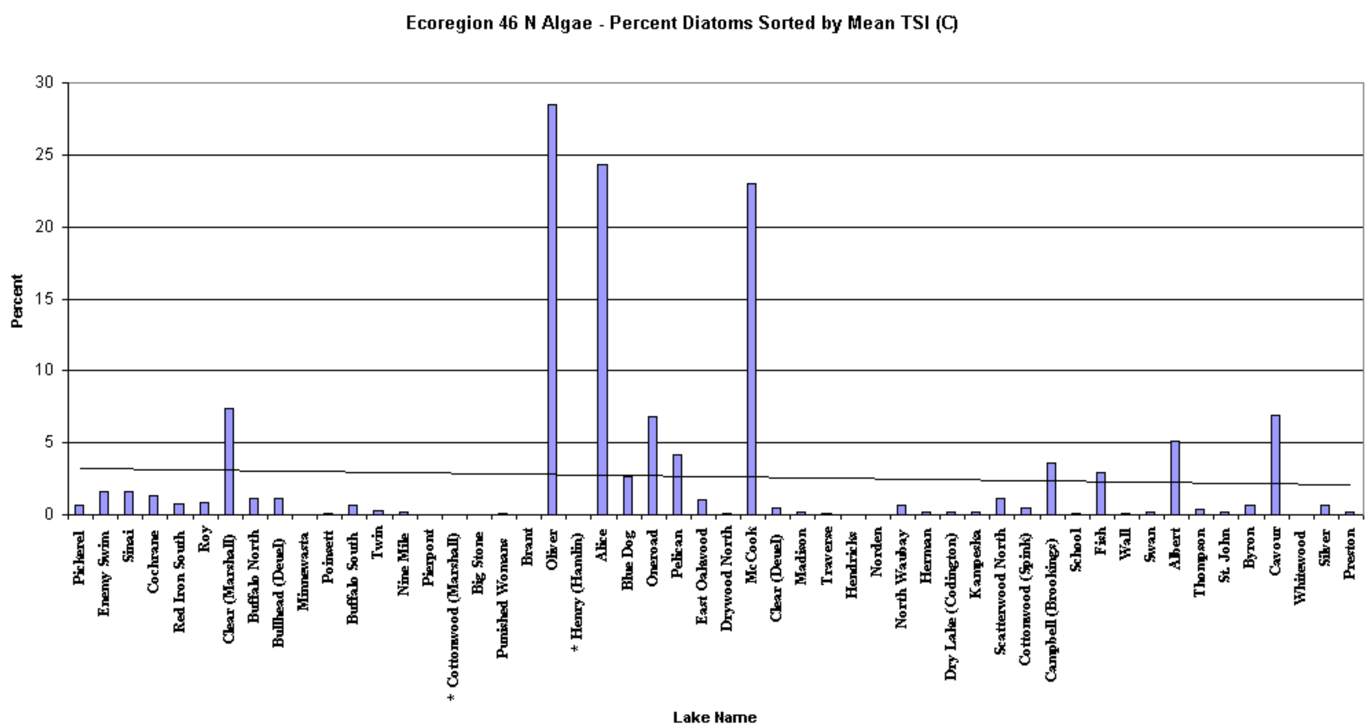

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Figure 2.24N. Ecoregion 46N Algae – Percent diatoms sorted by mean TSI (C).

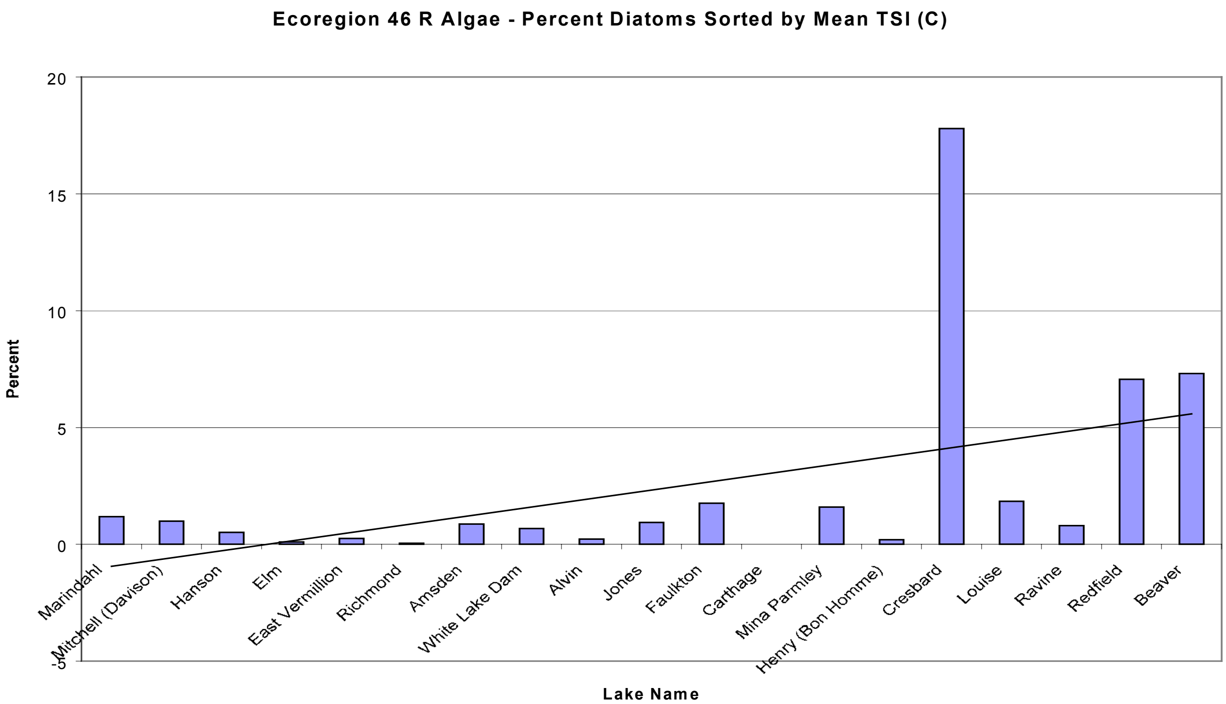

Figure 2.24R. Ecoregion 46R Algae – Percent diatoms sorted by mean TSI (C).

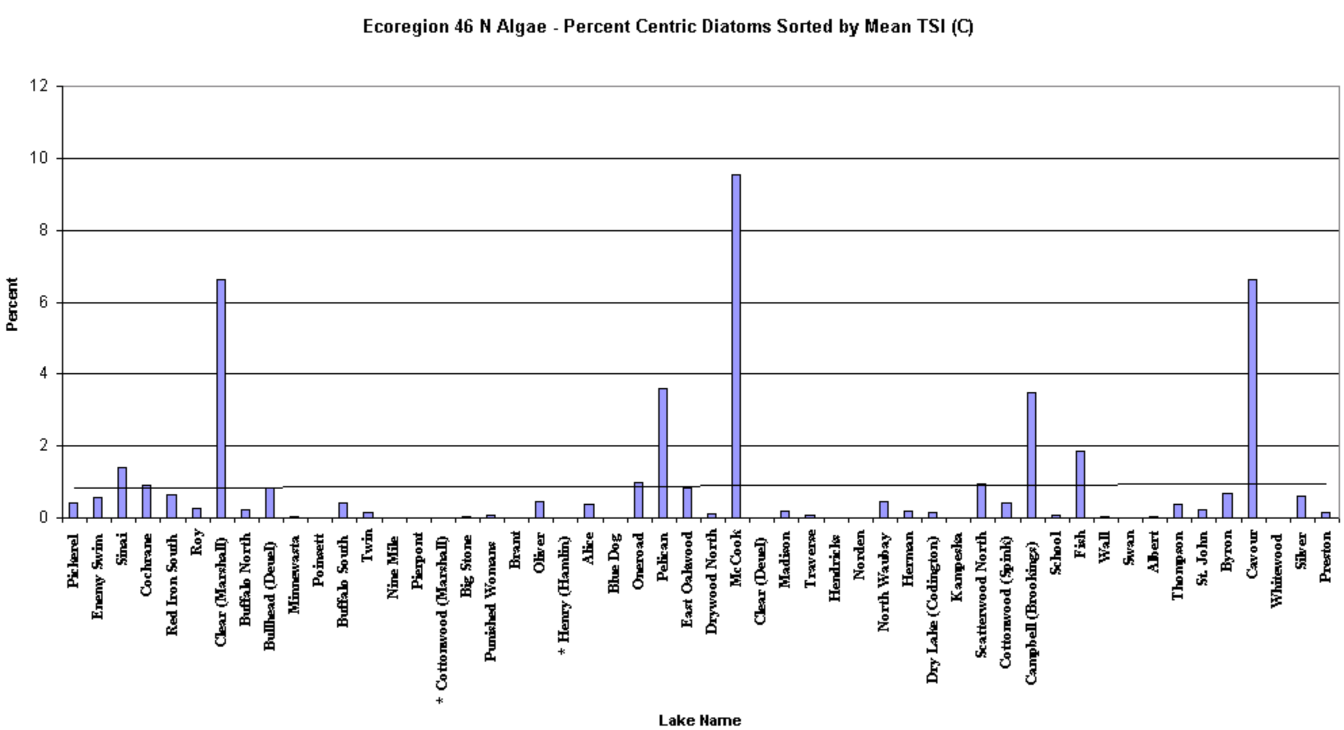

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Figure 2.25N. Ecoregion 46N Algae – Percent centric diatoms sorted by mean TSI (C).

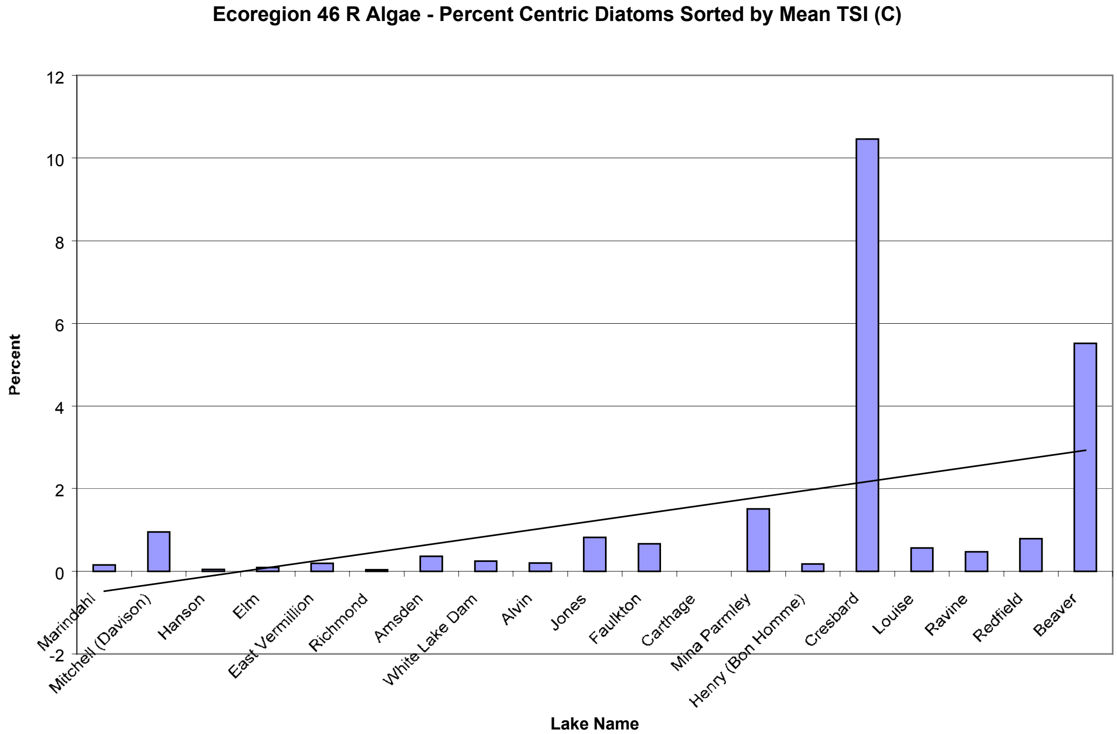

Figure 2.25R. Ecoregion 46R Algae – Percent centric diatoms sorted by mean TSI (C).

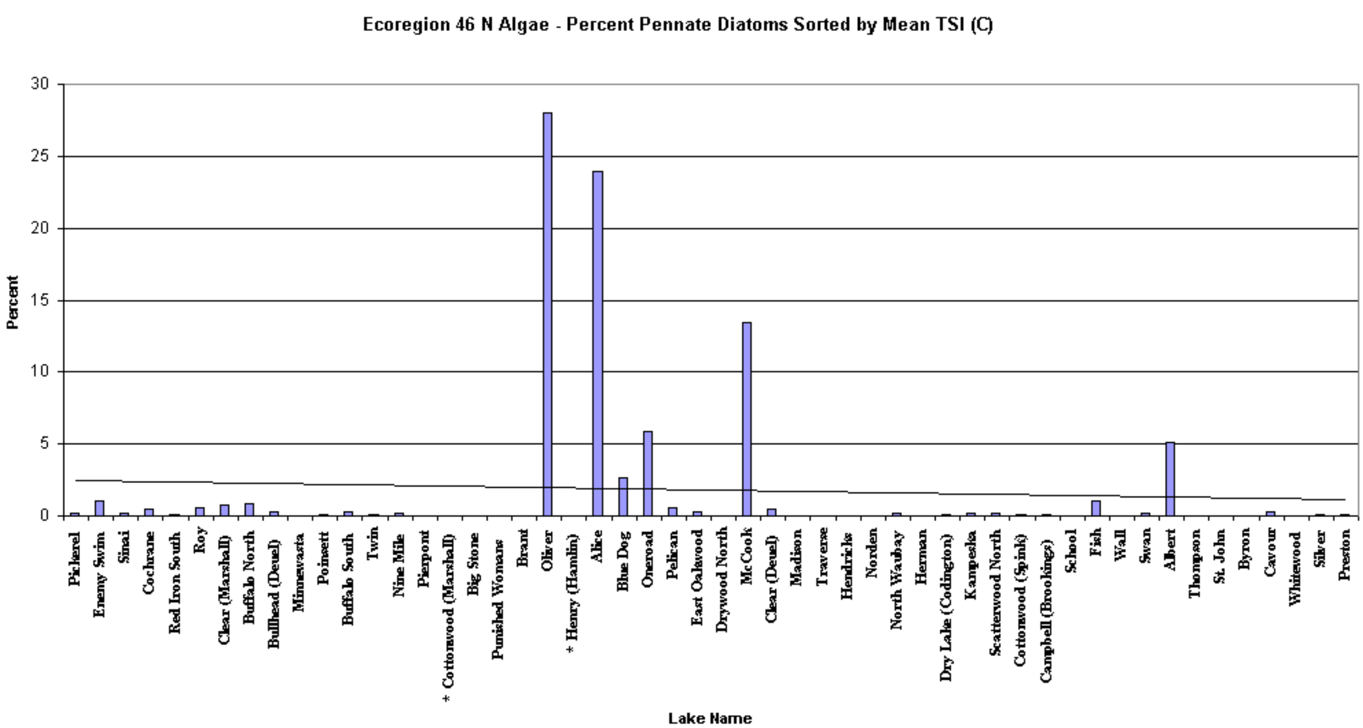

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Figure 2.26N. Ecoregion 46N Algae – Percent pennate diatoms sorted by mean TSI (C).

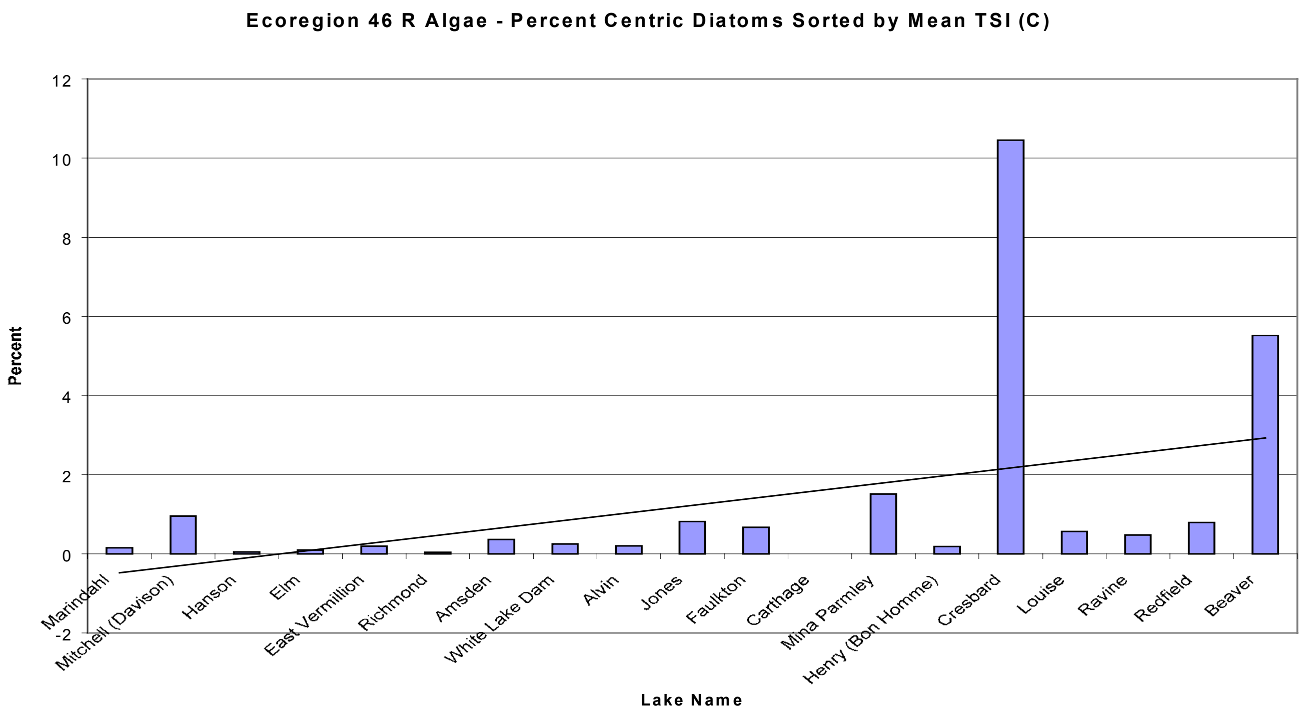

Figure 2.26R. Ecoregion 46R Algae – Percent pennate diatoms sorted by mean TSI (C).

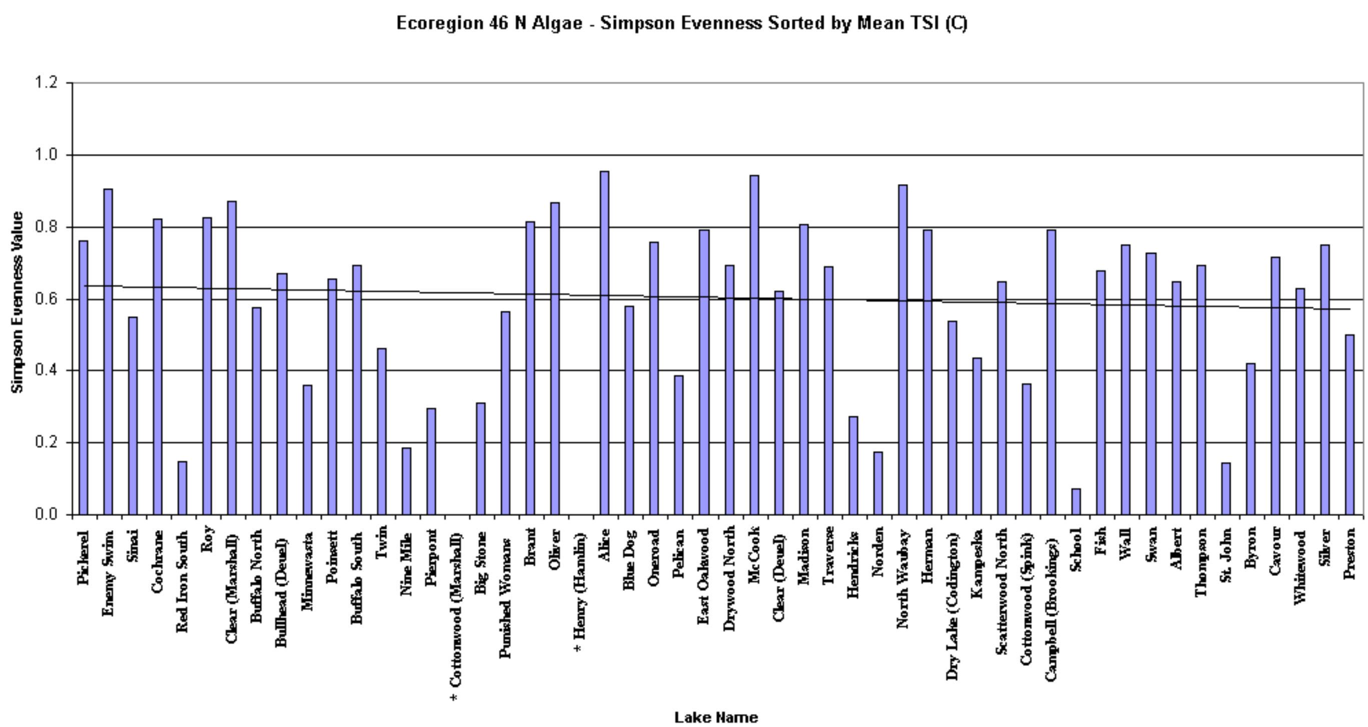

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Figure 2.27N. Ecoregion 46N Algae – Simpson evenness sorted by mean TSI (C).

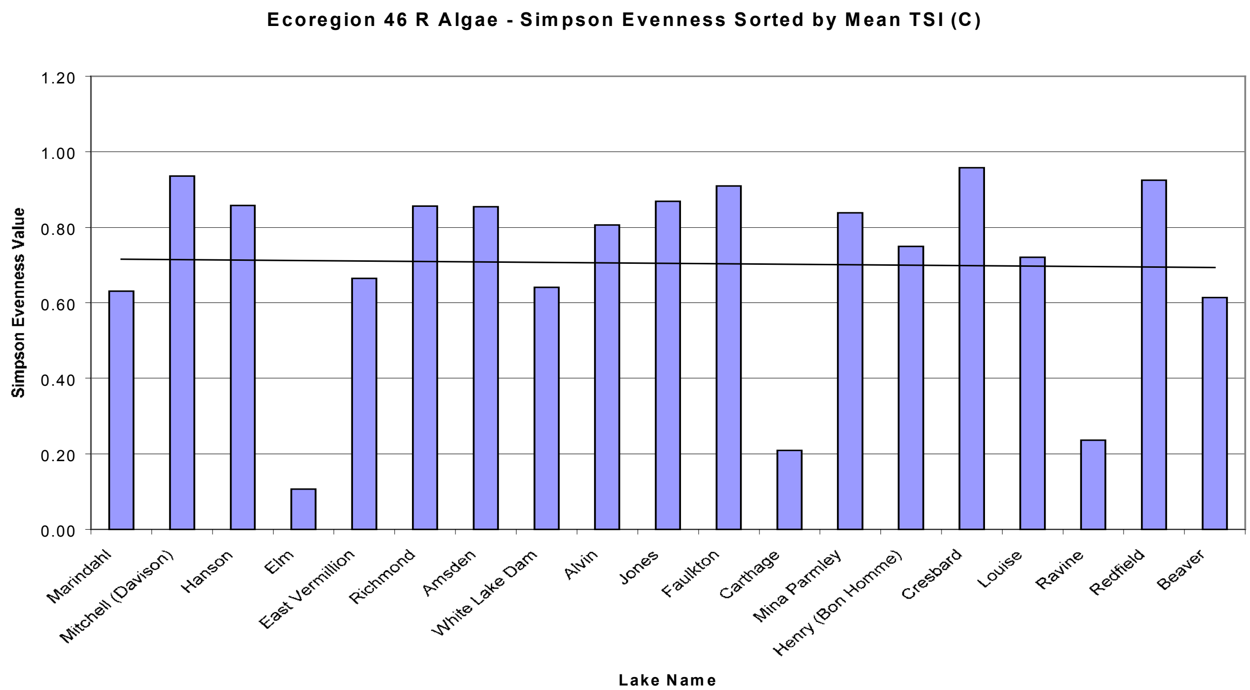

Figure 2.27R. Ecoregion 46R Algae – Simpson evenness sorted by mean TSI (C).

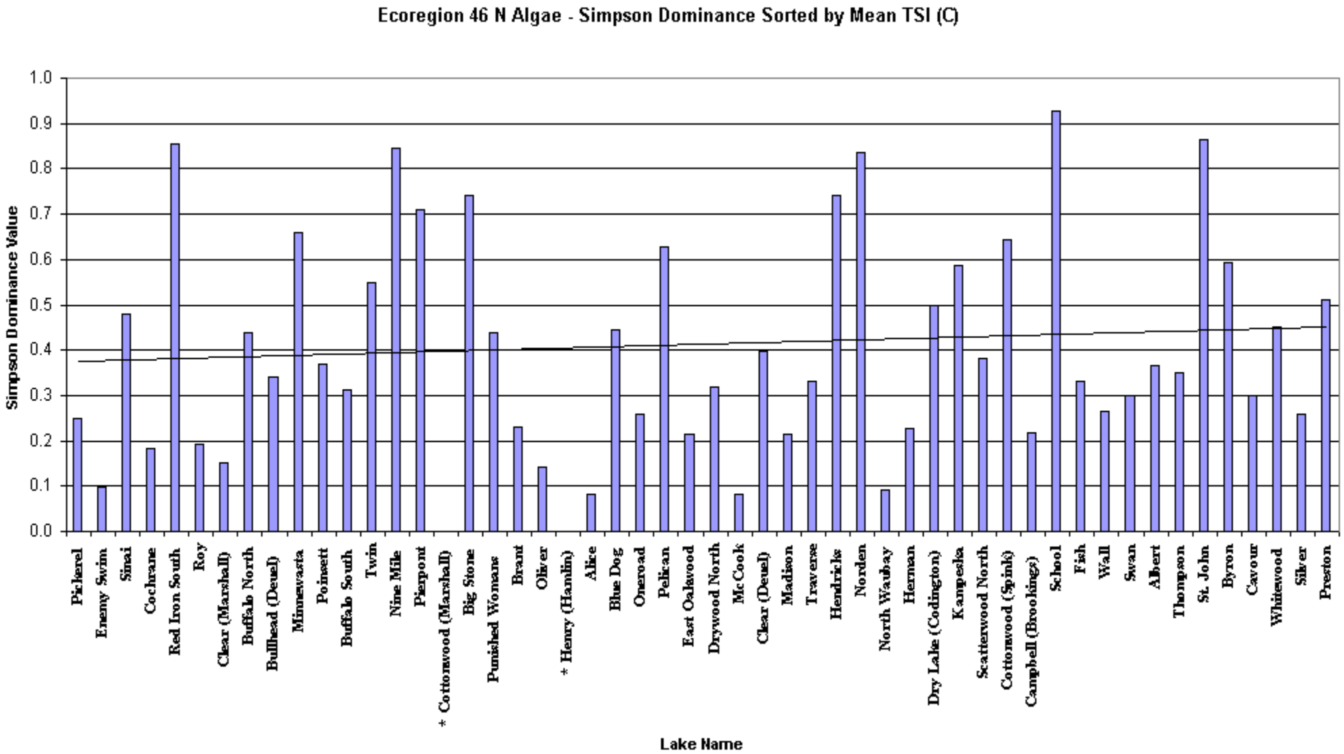

Figure 2.28N. Ecoregion 46N Algae – Simpson dominance sorted by Mean TSI (C).

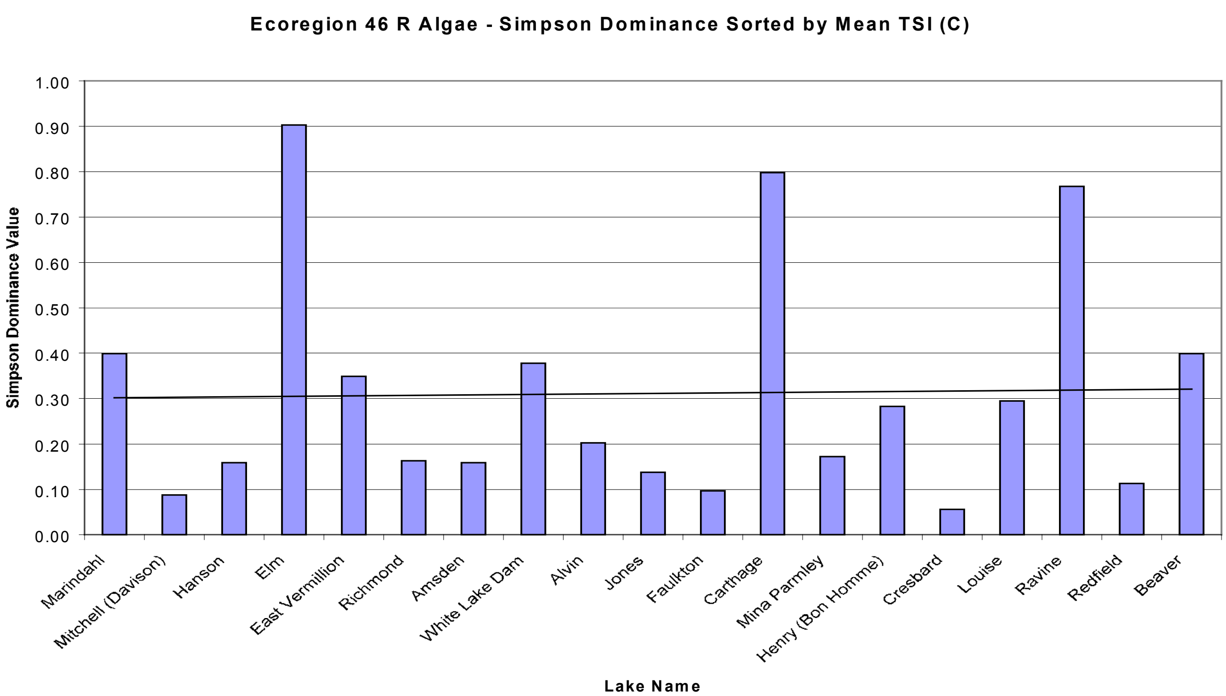

Figure 2.28R. Ecoregion 46R Algae – Simpson dominance sorted by Mean TSI (C).

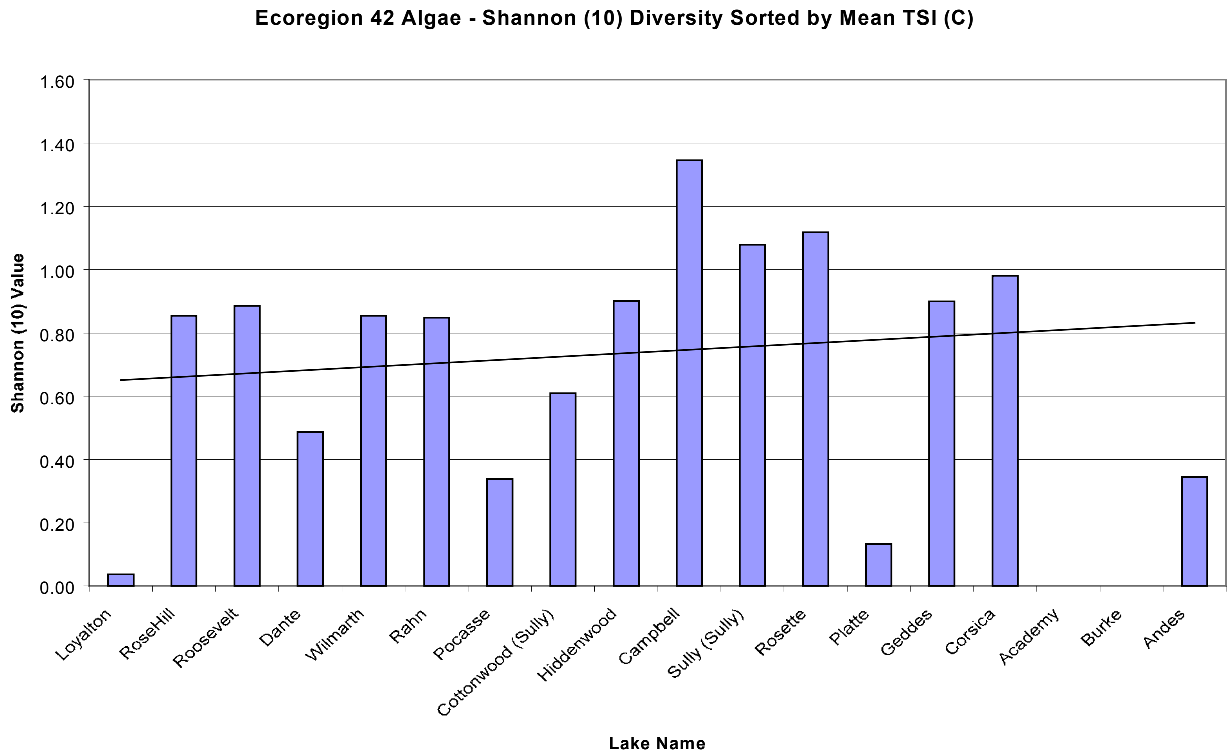

Figure 2.29. Ecoregion 42 Algae – Shannon (10) diversity sorted by mean TSI (C).

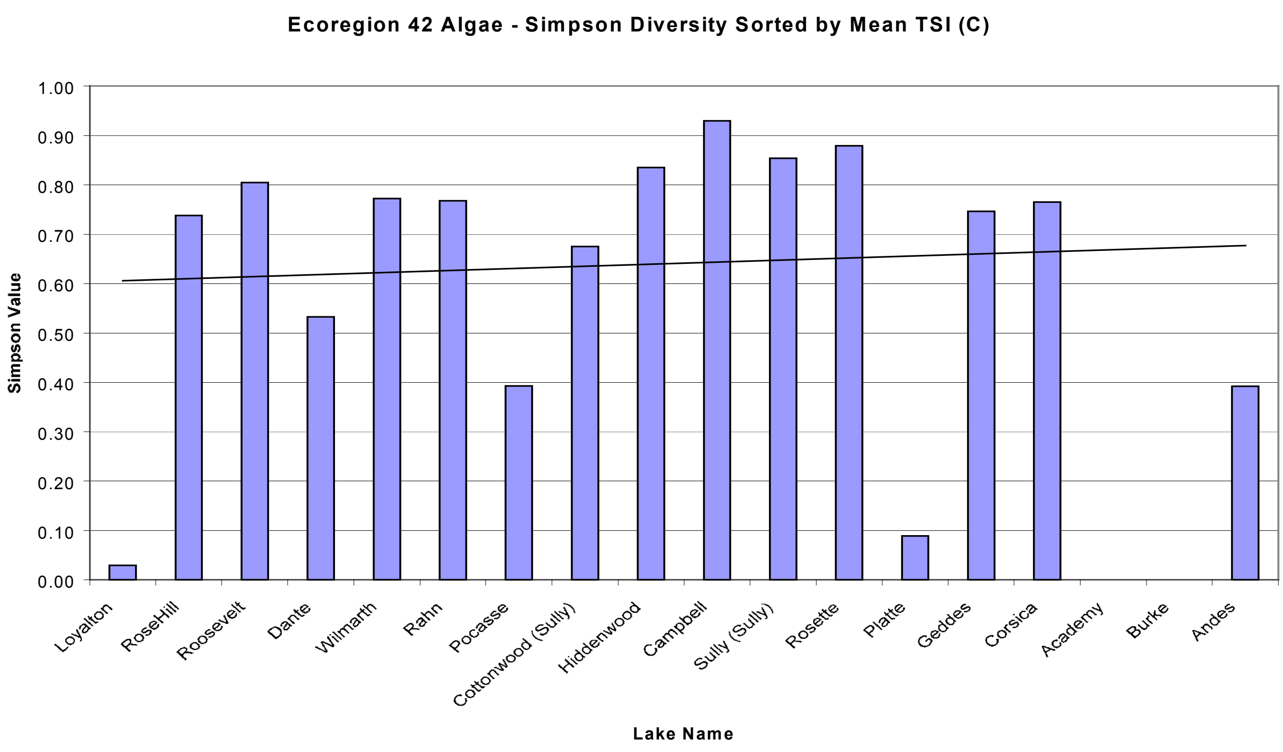

Figure 2.30. Ecoregion 42 Algae – Simpson diversity sorted by mean TSI (C).

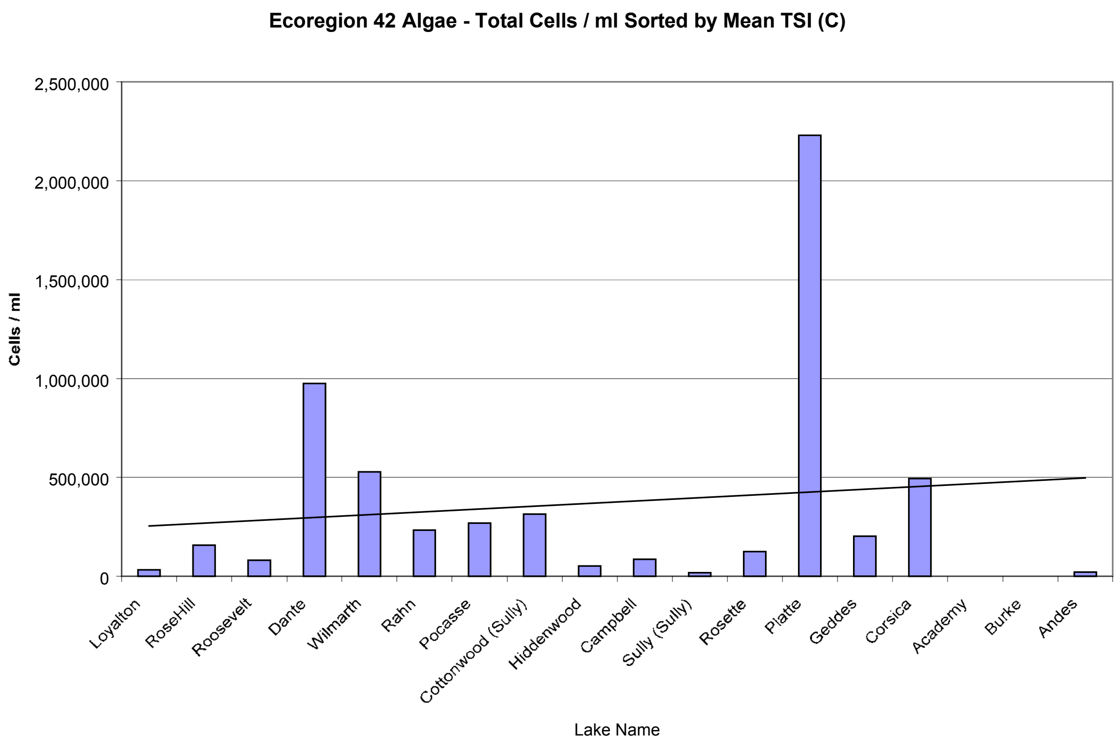

Figure 2.31. Ecoregion 42 Algae –Total cells/ml sorted by mean TSI (C).

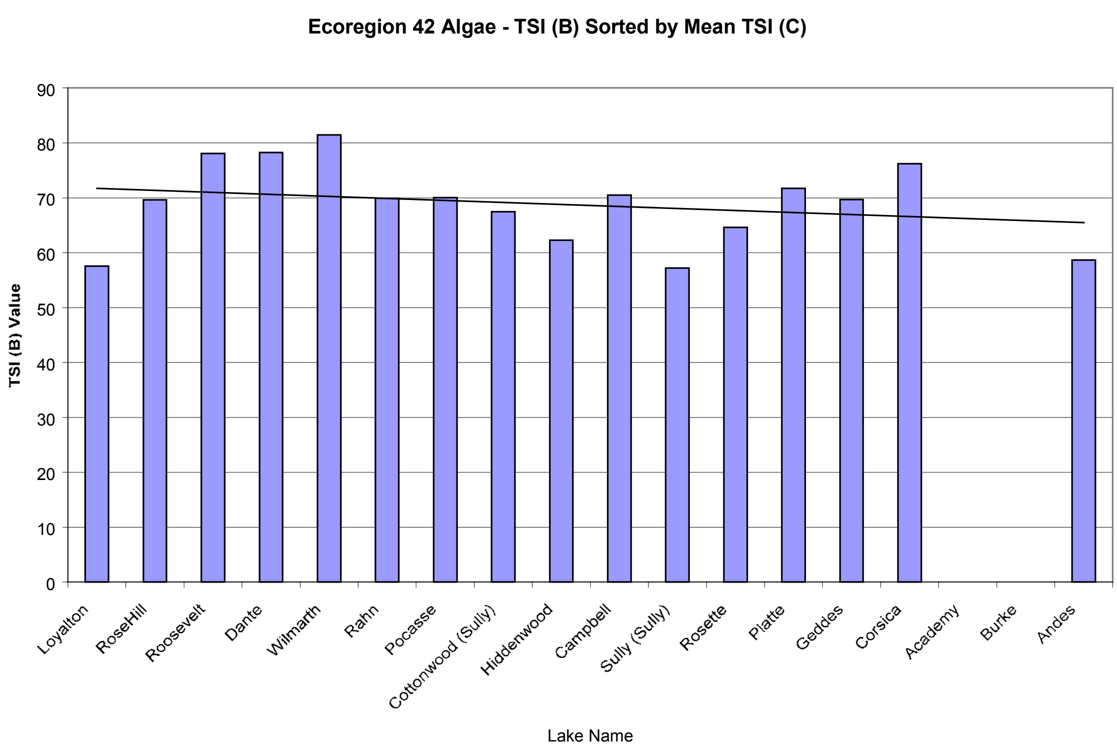

Figure 2.32. Ecoregion 42 Algae – TSI (biovolume) sorted by mean TSI (C).

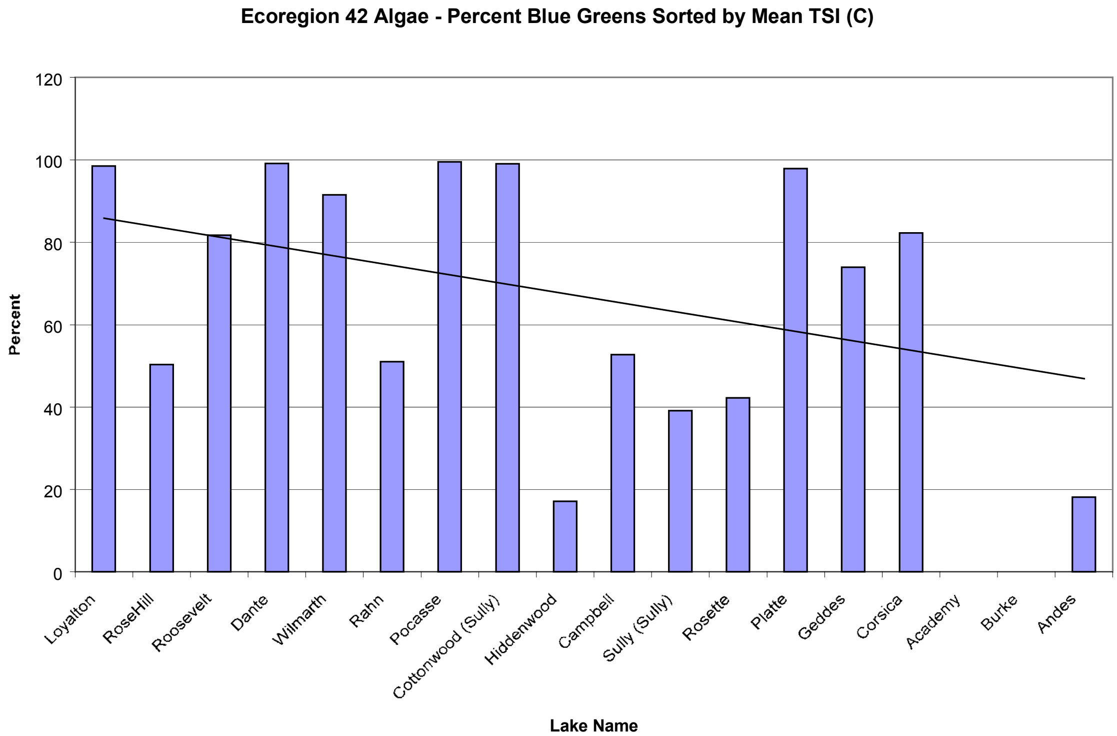

Figure 2.33. Ecoregion 42 Algae – Percent blue green algae sorted by mean TSI (C).

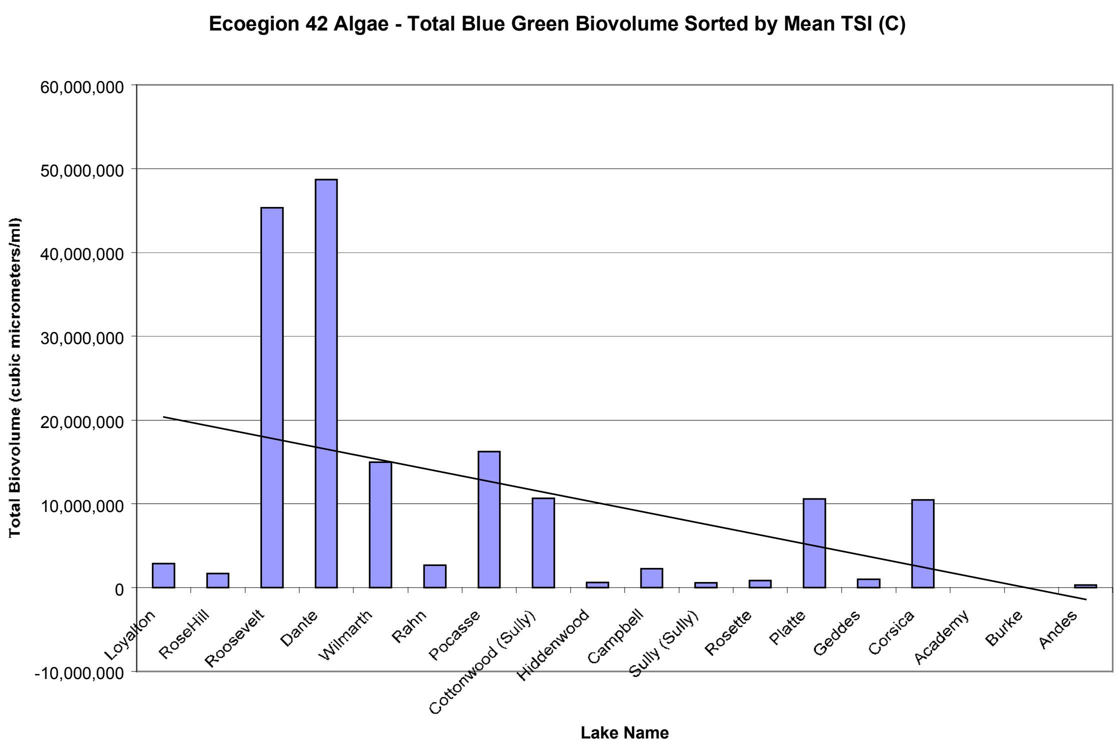

Figure 2.34. Ecoregion 42 Algae –Total blue green algae biovolume sorted by mean TSI (C).

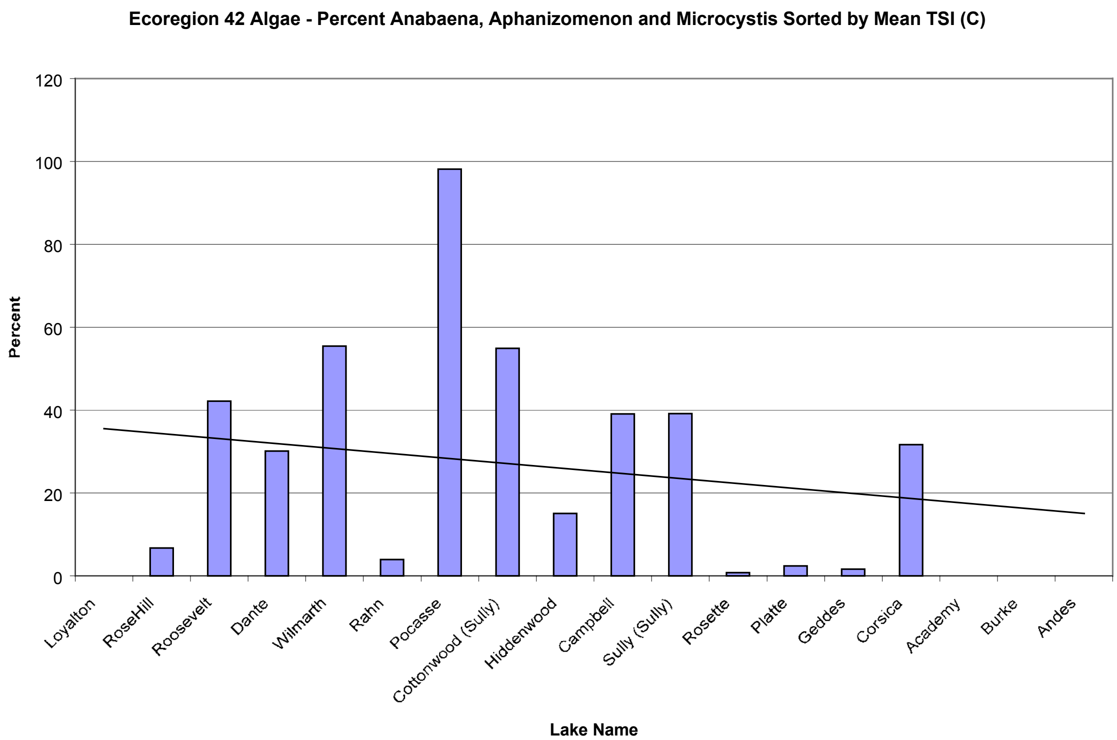

Figure 2.35. Ecoregion 42 Algae –Percent Anabaena, Aphanizomenon and Microcystis sorted by mean TSI (C).

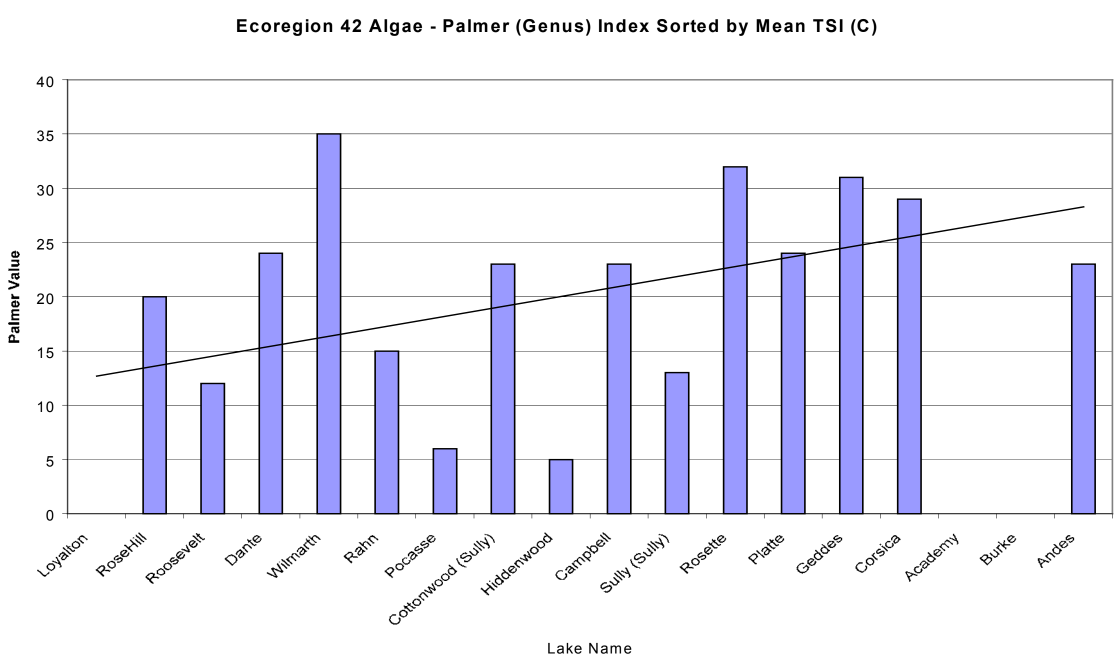

Figure 2.36. Ecoregion 42 Algae –Palmer index (Genus) sorted by mean TSI (C).

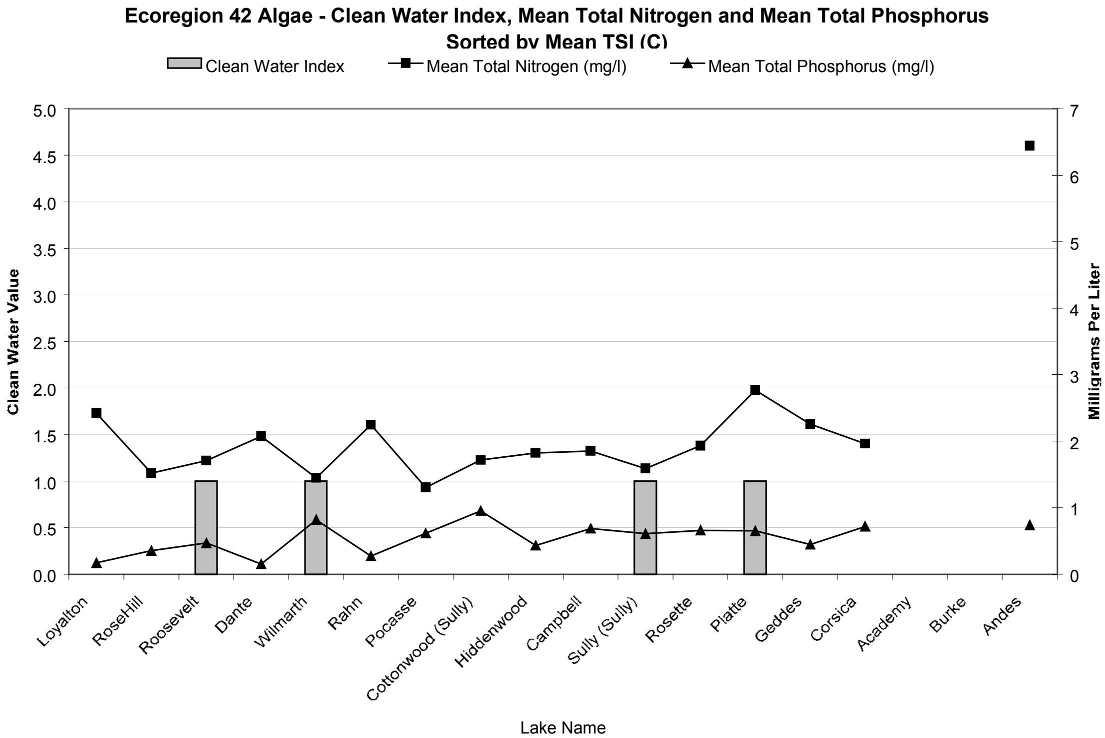

Figure 2.37. Ecoregion 42 Algae –Clean water index, mean total nitrogen and mean total phosphorus sorted by mean TSI (C).

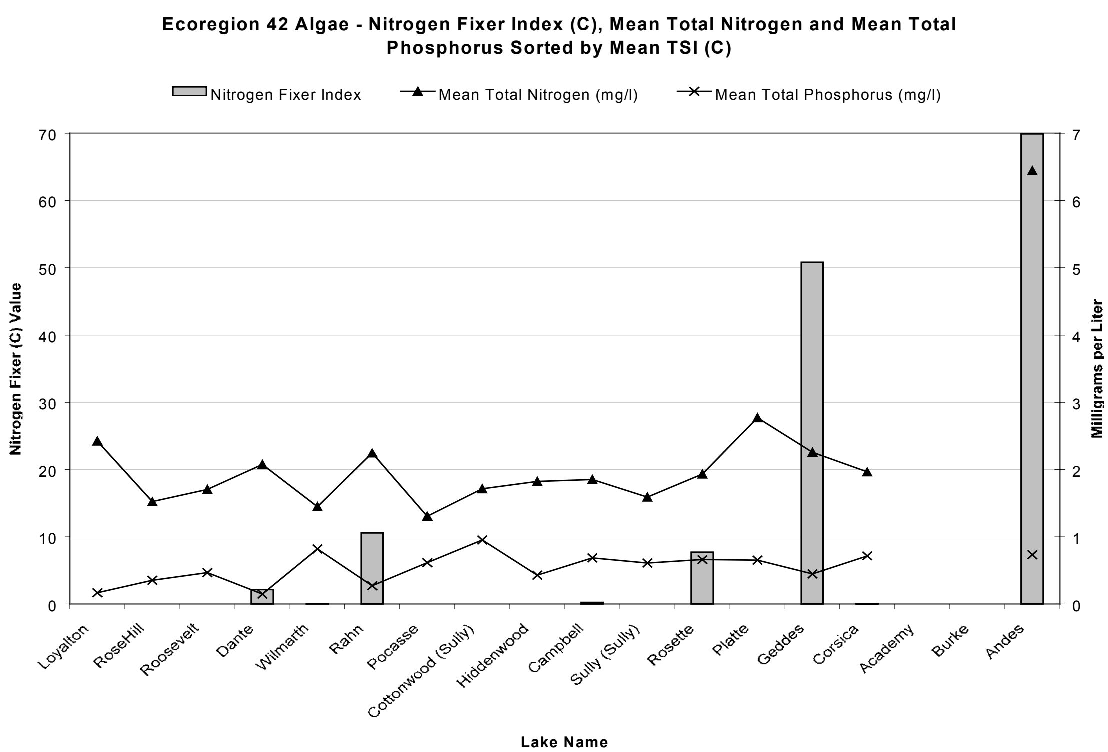

Figure 2.38. Ecoregion 42 Algae –Nitrogen fixer index (cells/ml), mean total nitrogen and mean total phosphorus sorted by mean TSI (C).

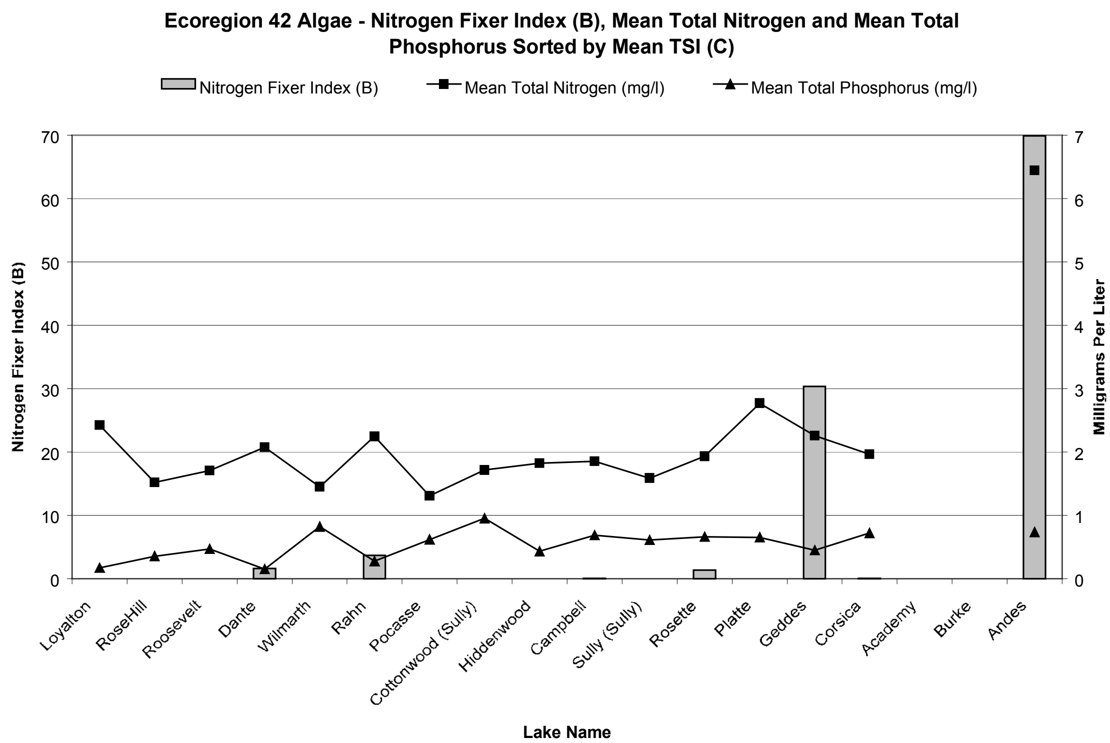

Figure 2.39. Ecoregion 42 Algae – Nitrogen fixer index (biovolume), mean total nitrogen and mean total phosphorus sorted by mean TSI (C).

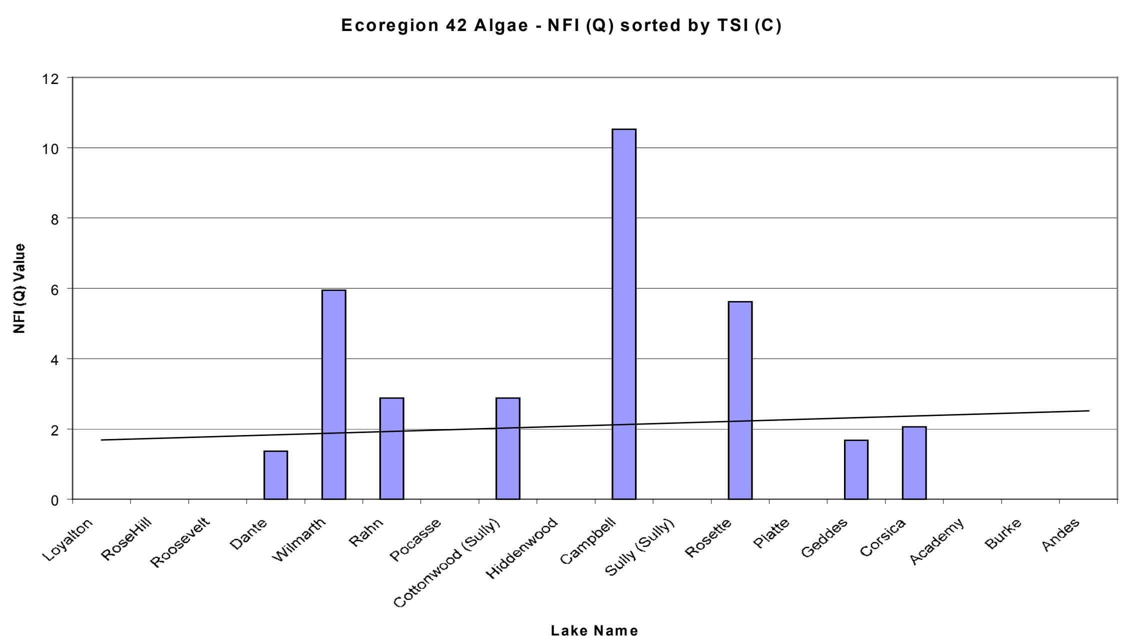

Figure 2.40. Ecoregion 42 Algae – Nitrogen fixer index (quotient), sorted by mean TSI (C).

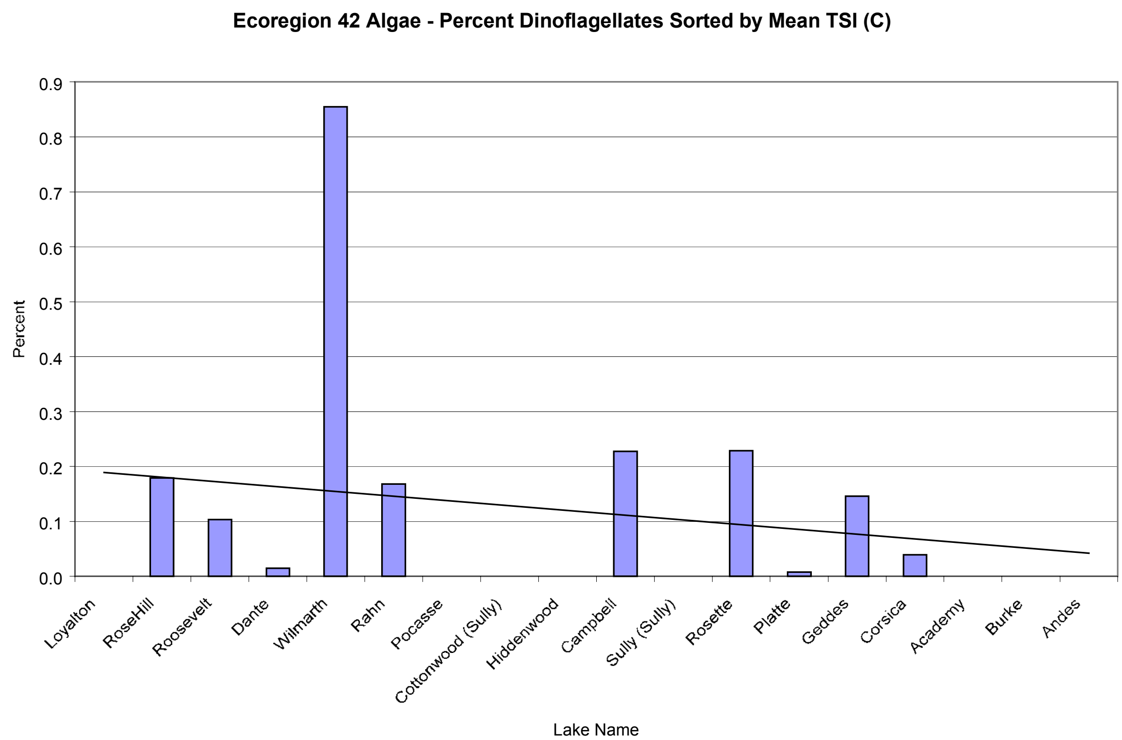

Figure 2.41. Ecoregion 42 Algae – Percent dinoflagellates sorted by mean TSI (C).

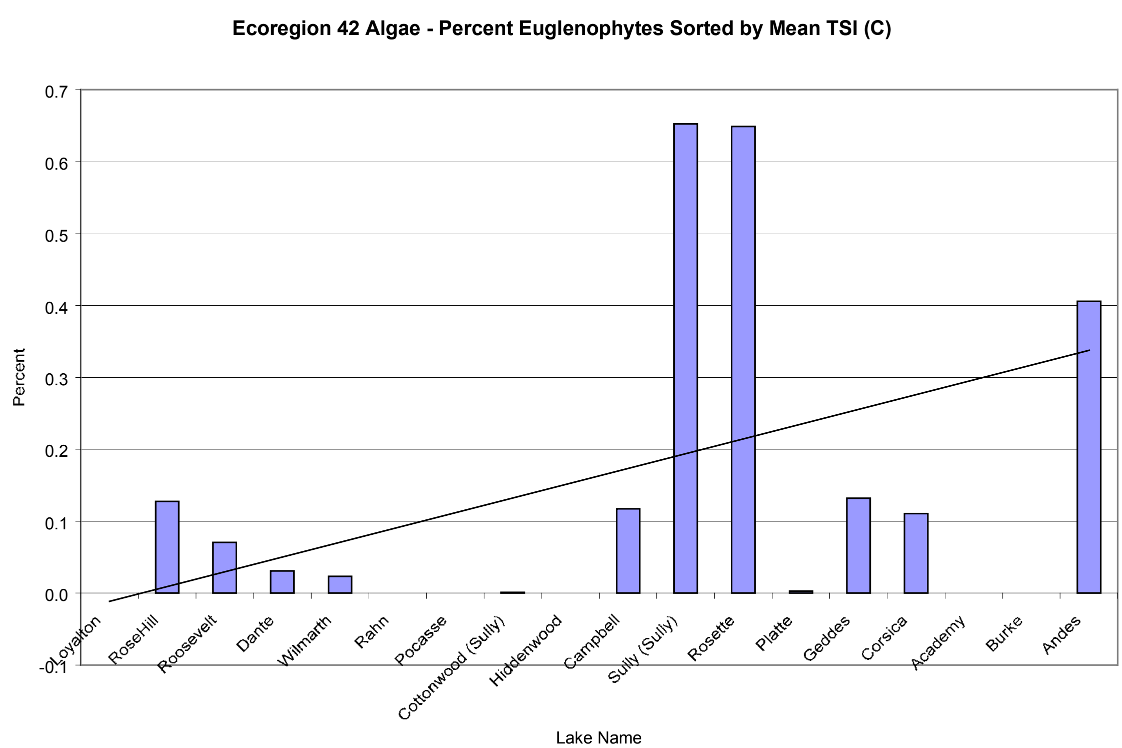

Figure 2.42. Ecoregion 42 Algae –Percent euglenophytes sorted by mean TSI (C).

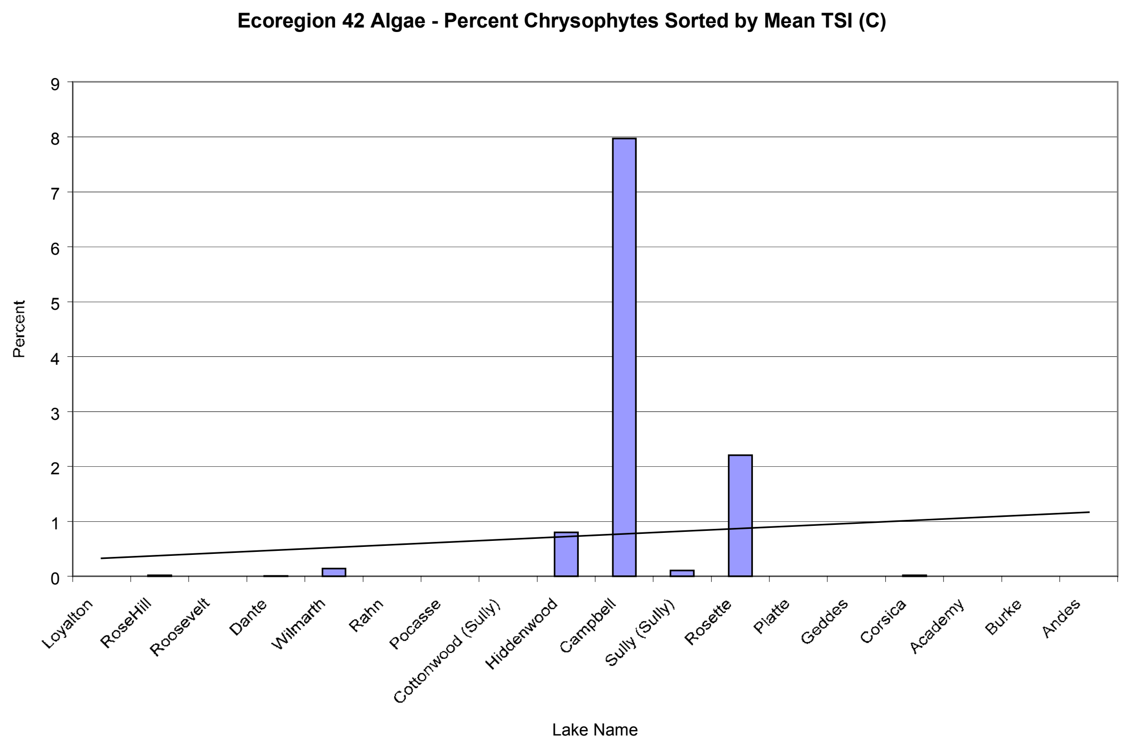

Figure 2.43. Ecoregion 42 Algae –Percent chrysophytes sorted by mean TSI (C).

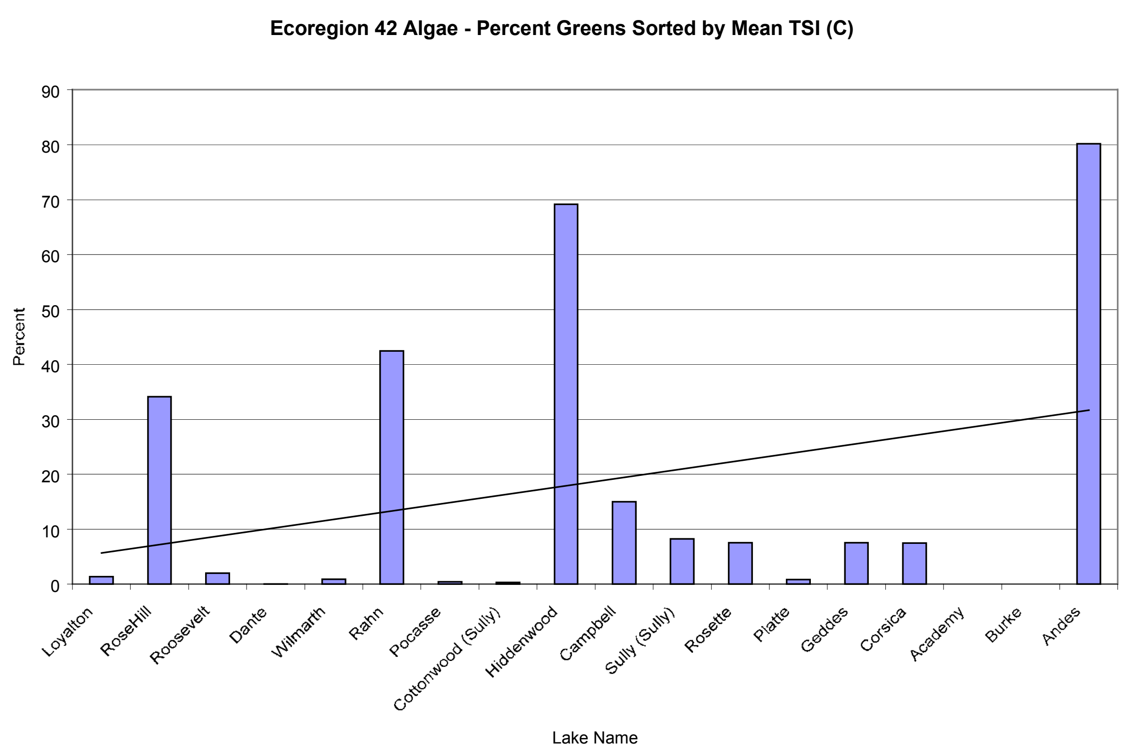

Figure 2.44. Ecoregion 42 Algae –Percent green algae sorted by mean TSI (C).

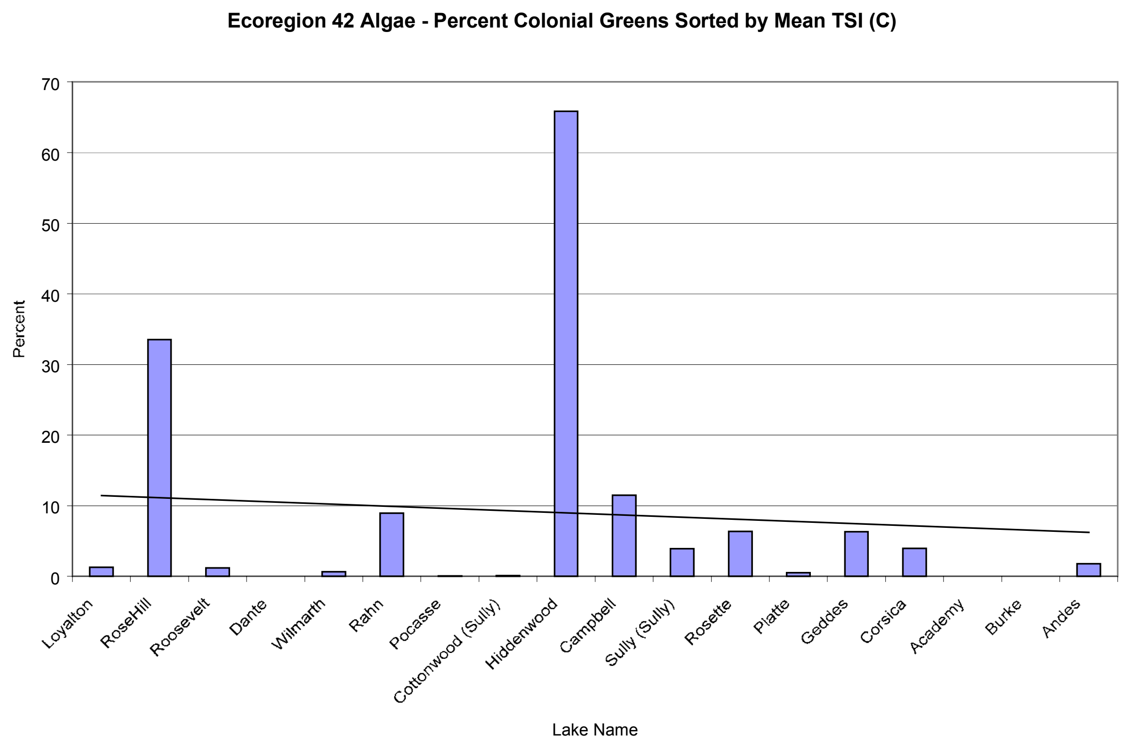

Figure 2.45. Ecoregion 42 Algae –Percent colonial green algae sorted by mean TSI (C).

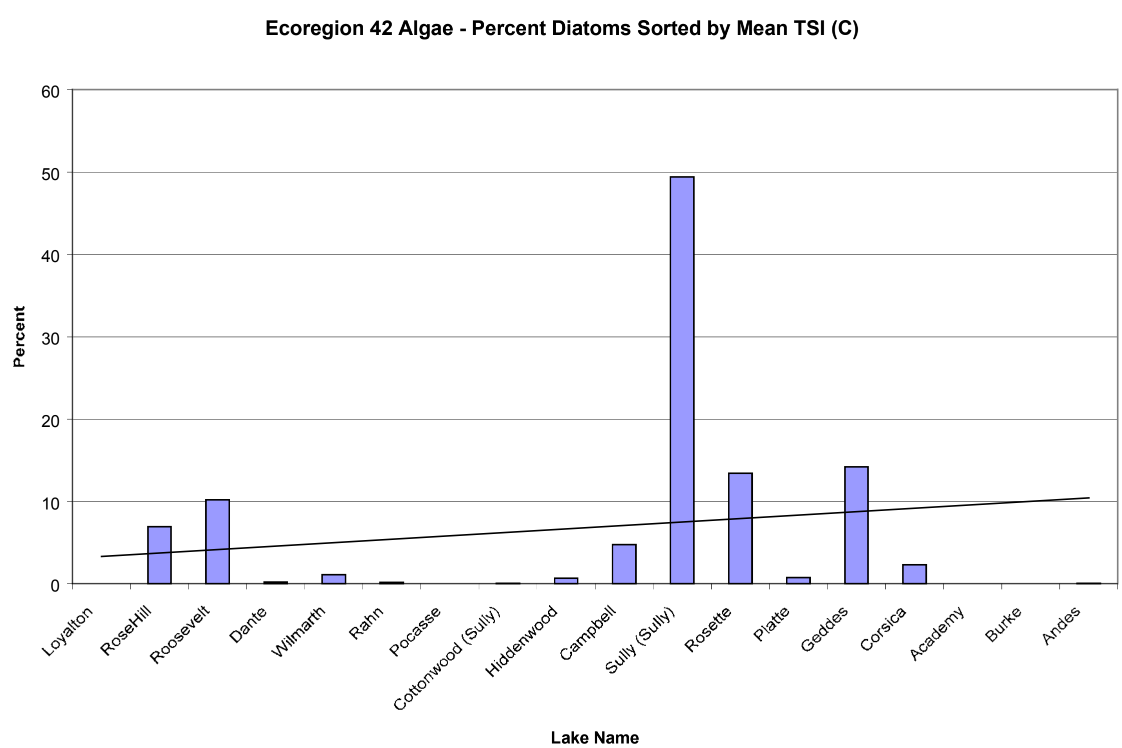

Figure 2.46. Ecoregion 42 Algae –Percent diatoms sorted by mean TSI (C).

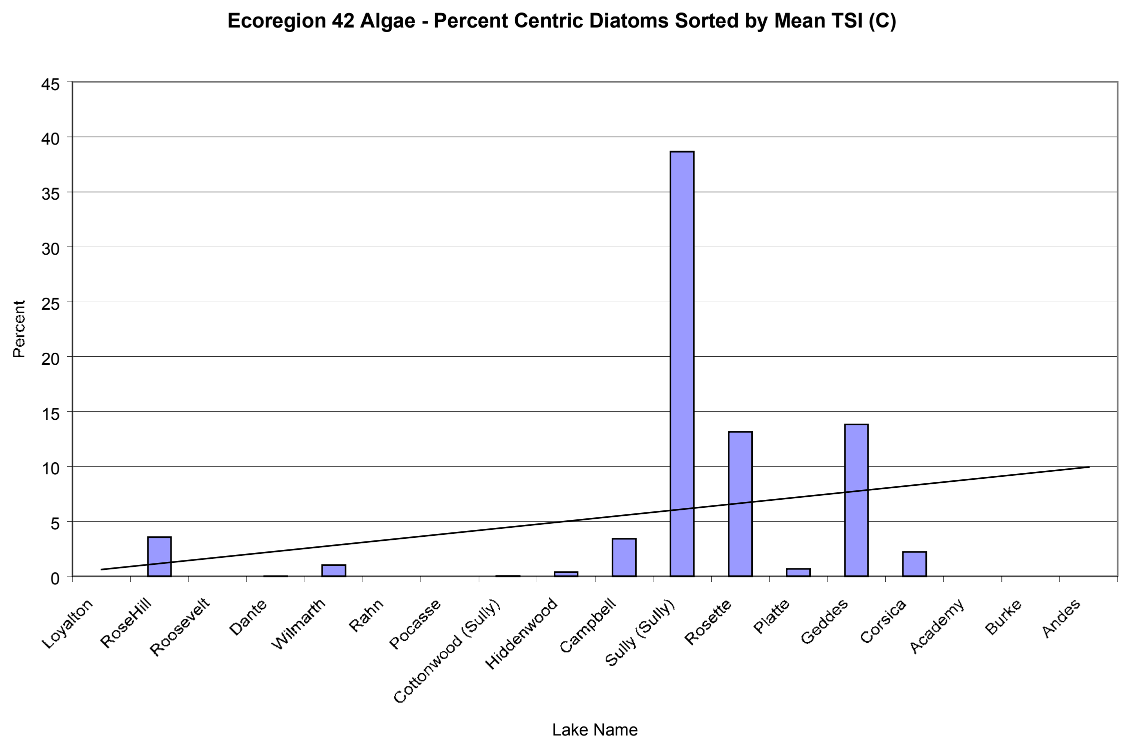

Figure 2.47. Ecoregion 42 Algae –Percent centric diatoms sorted by mean TSI (C).

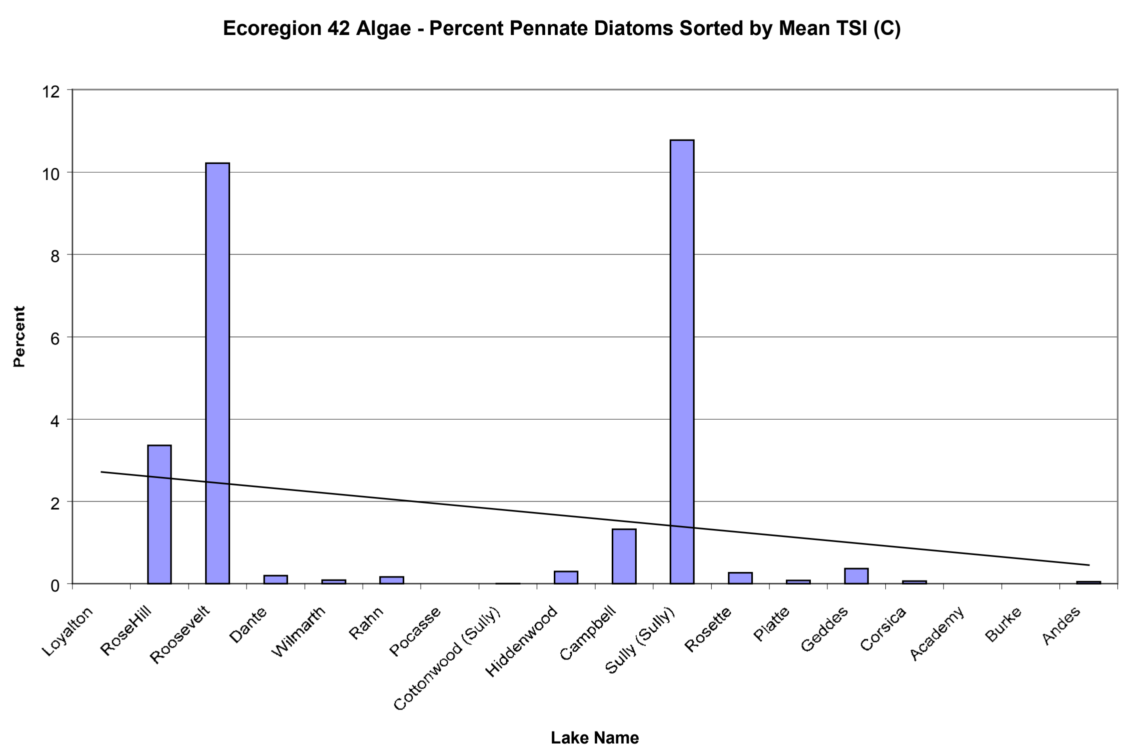

Figure 2.48. Ecoregion 42 Algae –Percent pennate diatoms sorted by mean TSI (C).

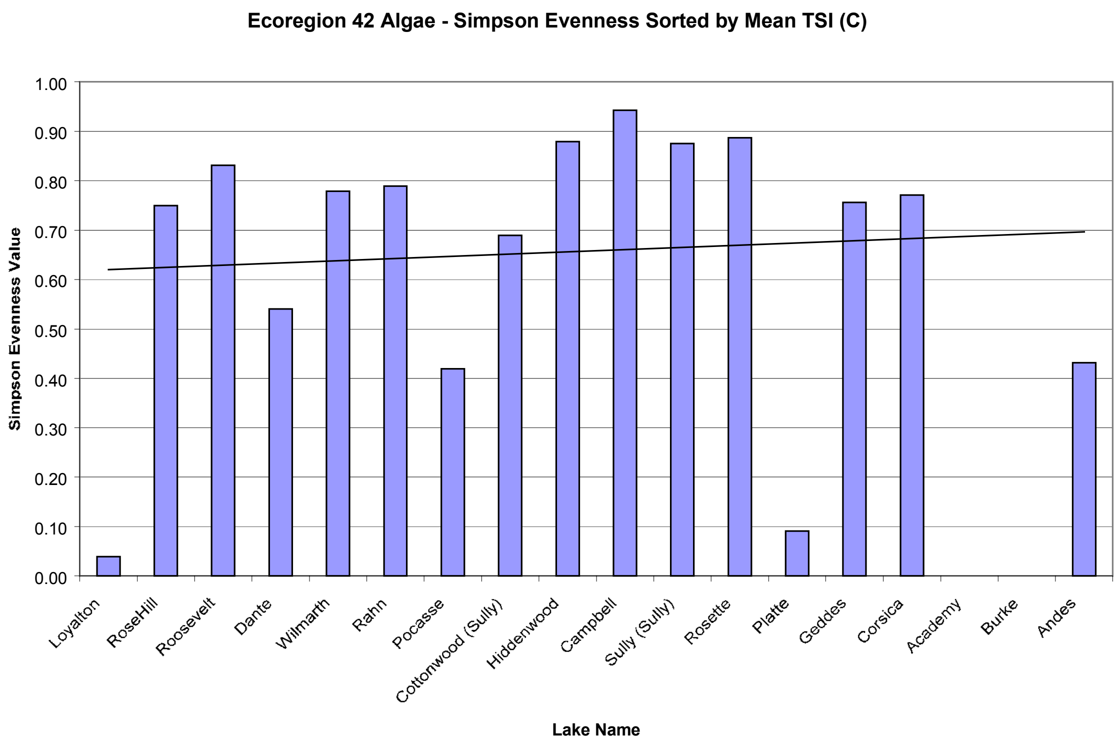

Figure 2.49. Ecoregion 42 Algae –Simpson evenness sorted by mean TSI (C).

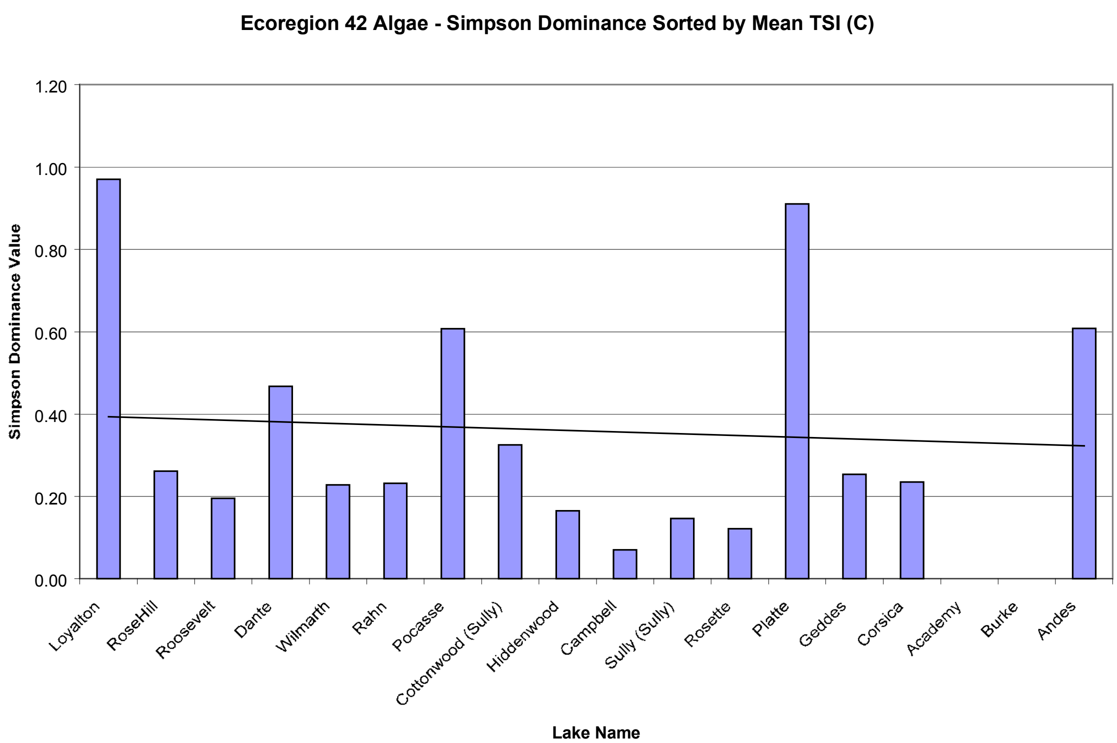

Figure 2.50. Ecoregion 42 Algae –Simpson dominance sorted by mean TSI (C).

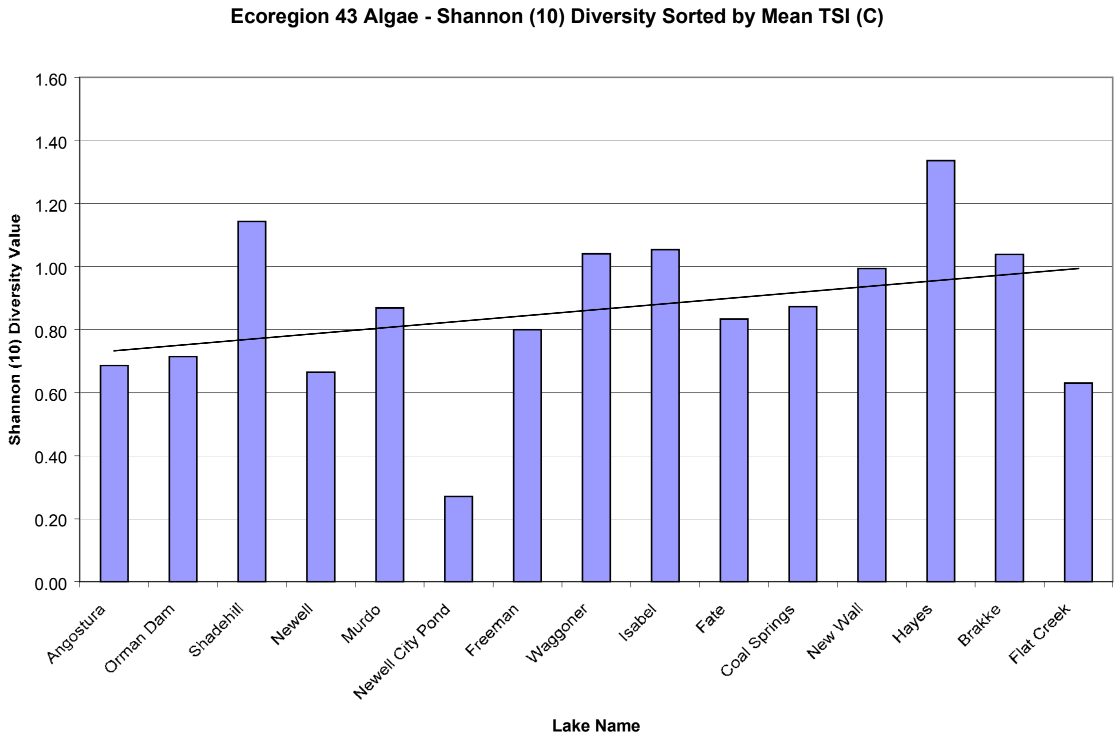

Figure 2.51. Ecoregion 43 Algae – Shannon (10) diversity sorted by mean TSI (C)

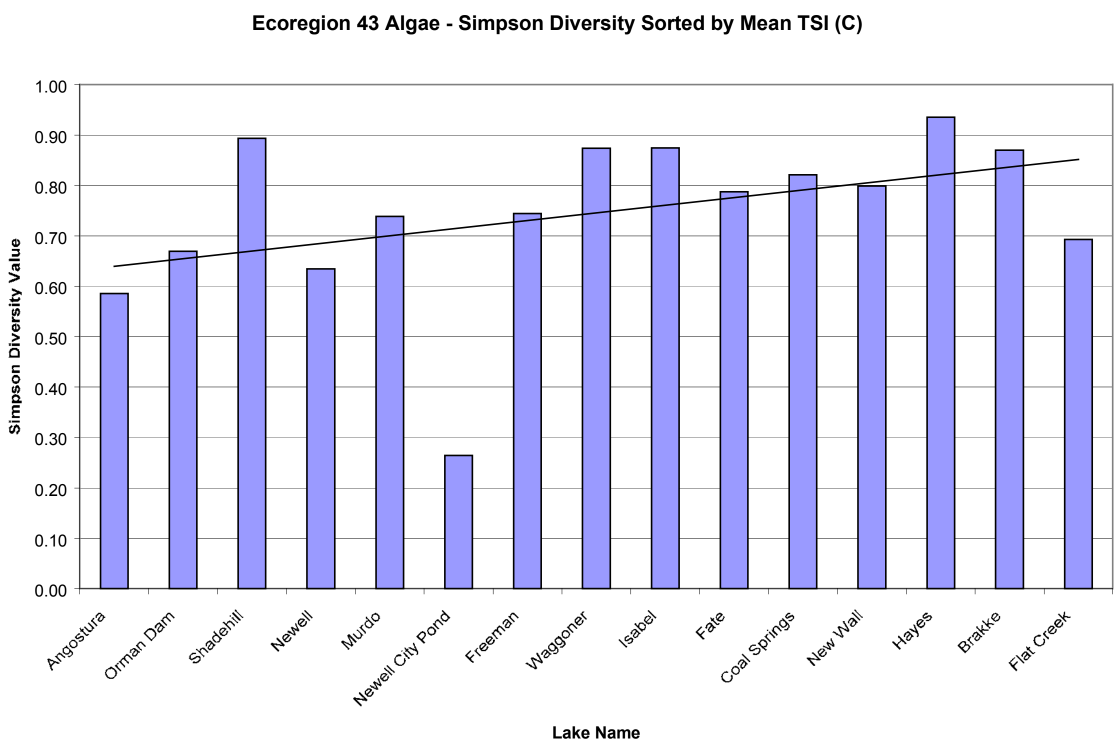

Figure 2.52. Ecoregion 43 Algae – Simpson diversity sorted by mean TSI (C).

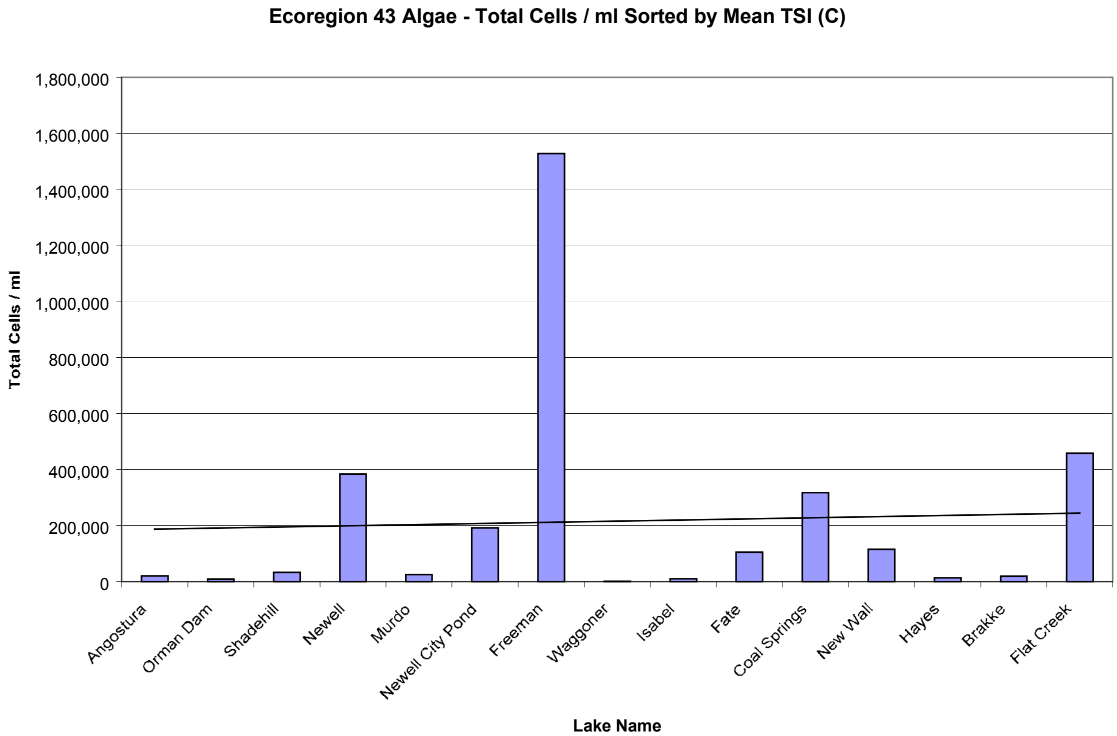

Figure 2.53. Ecoregion 43 Algae – Total cell/ml sorted by mean TSI (C).

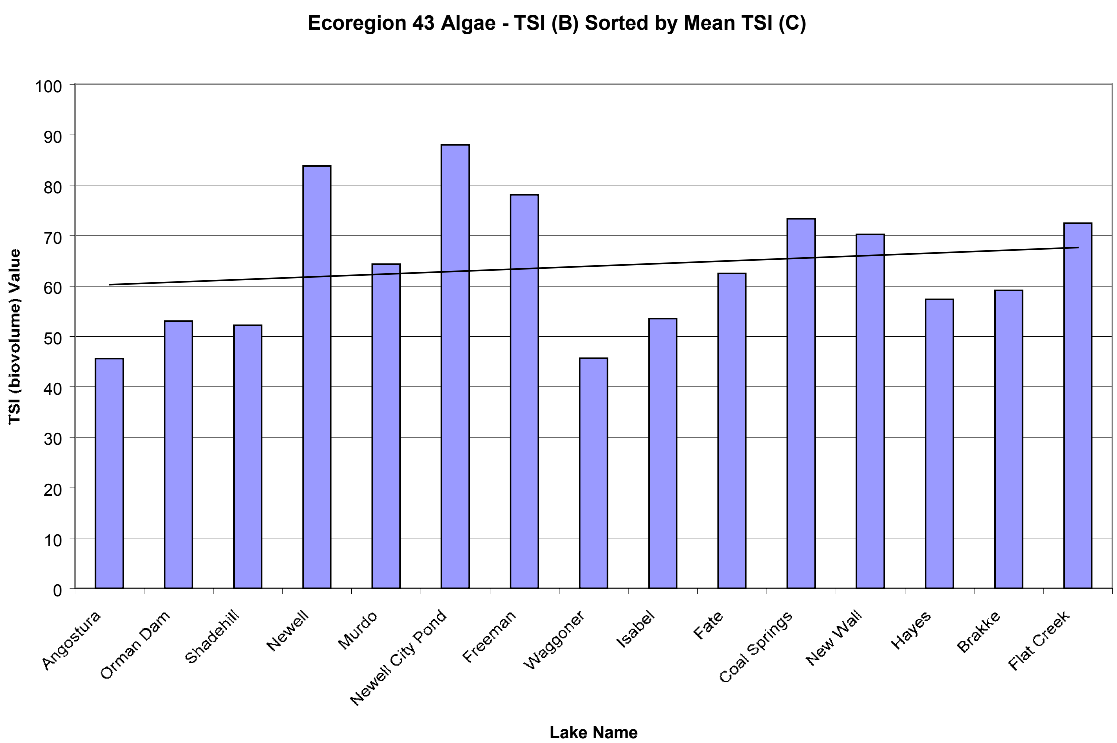

Figure 2.54. Ecoregion 43 Algae – TSI (biovolume) sorted by mean TSI (C).

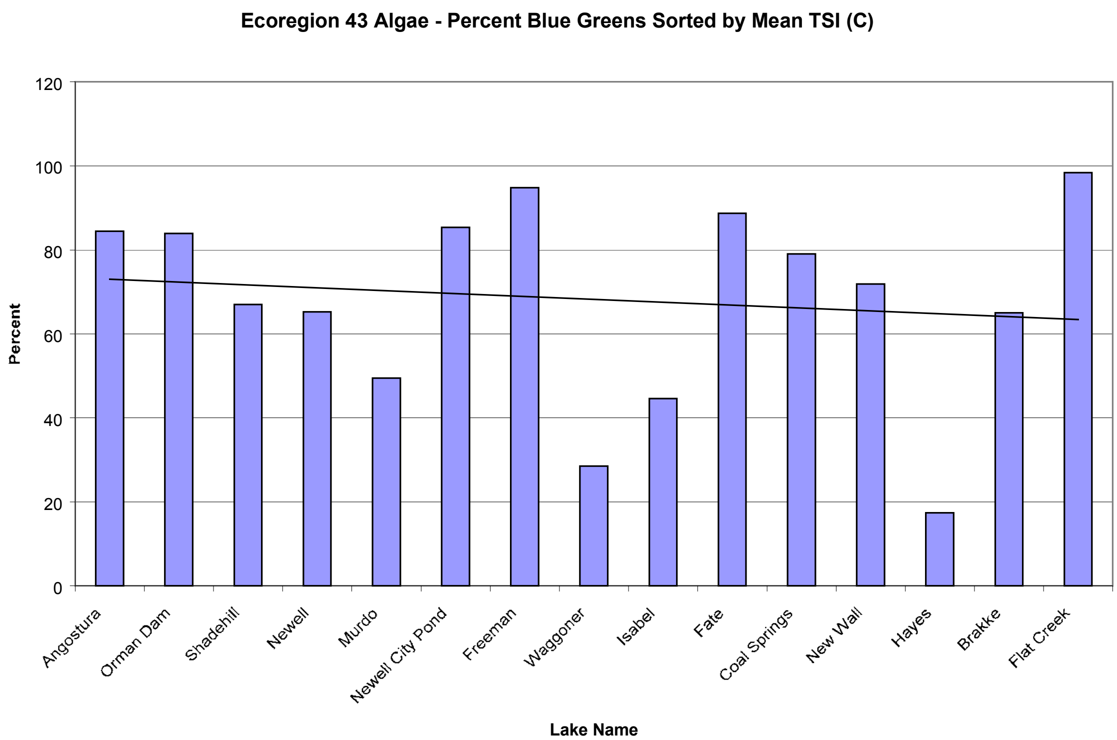

Figure 2.55. Ecoregion 43 Algae – Percent blue green algae sorted by mean TSI (C).

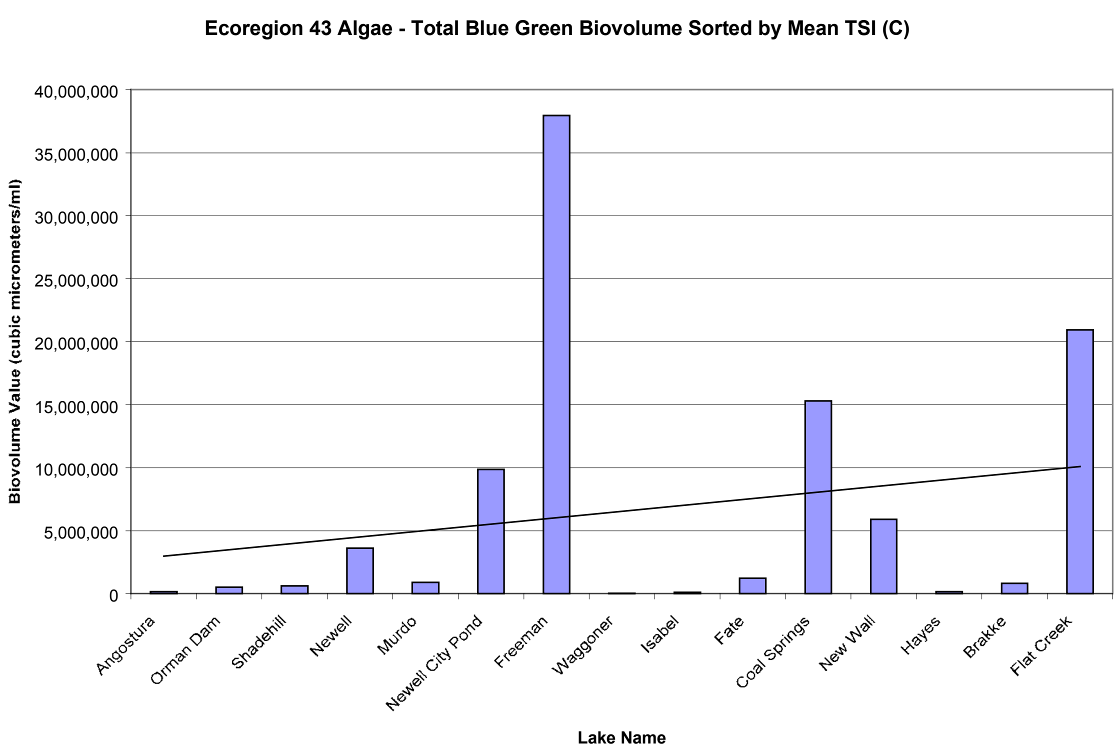

Figure 2.56. Ecoregion 43 Algae – Total blue green algae biovolume sorted by mean TSI (C)

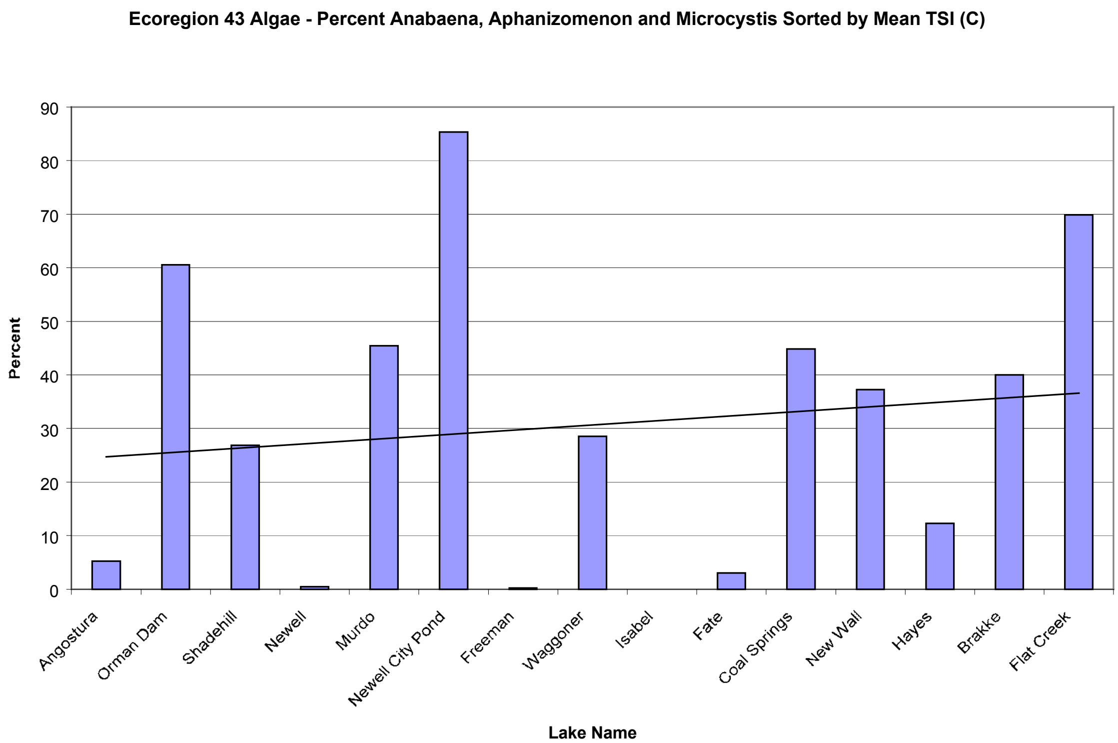

Figure 2.57. Ecoregion 43 Algae – Percent Anabaena, Aphanizomenon and Microcystis sorted by mean TSI (C).

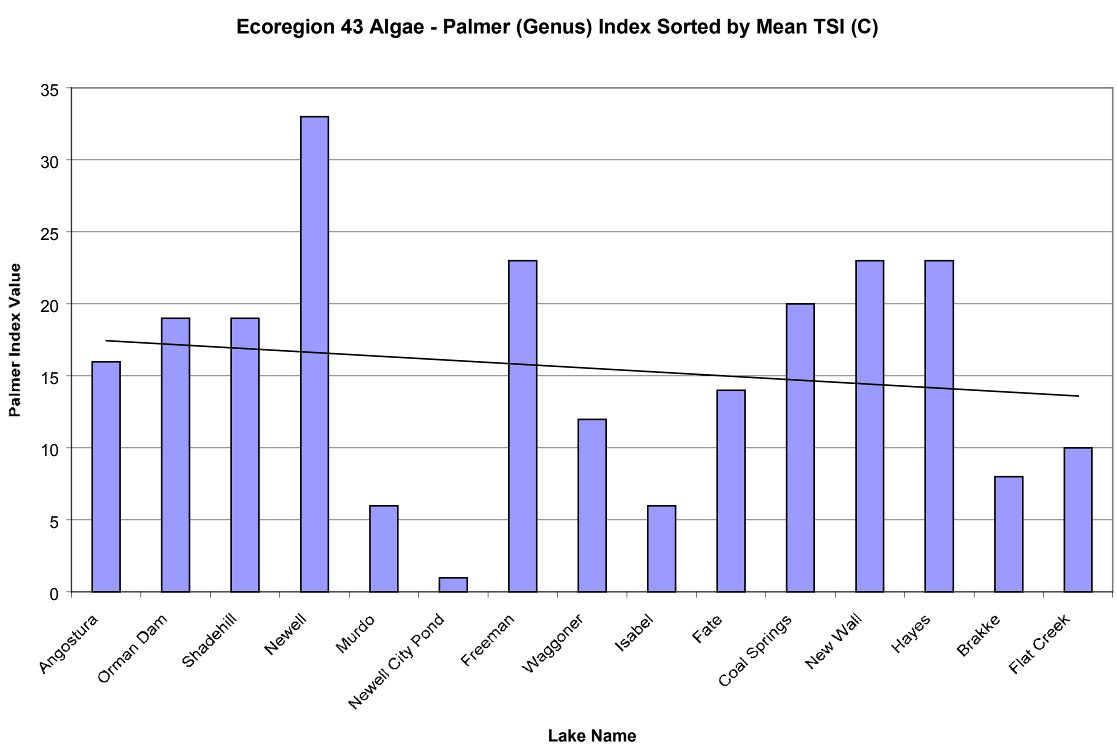

Figure 2.58. Ecoregion 43 Algae – Palmer index (Genus) sorted by mean TSI (C).

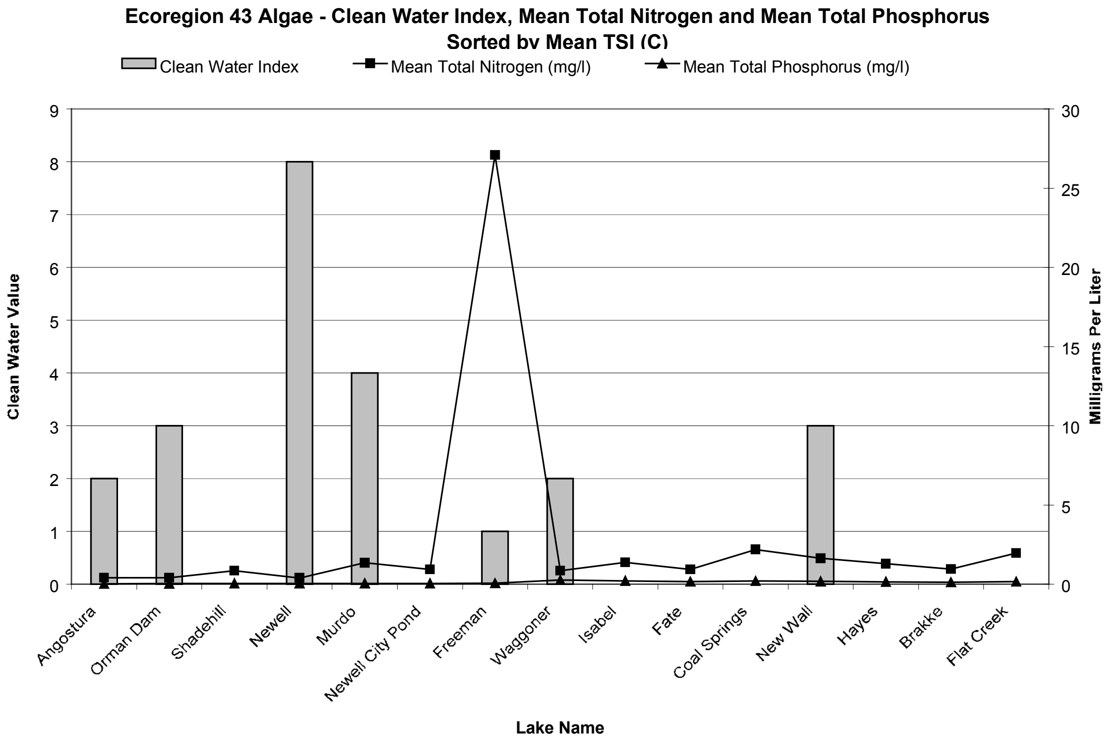

Figure 2.59. Ecoregion 43 Algae – Clean water index, mean total nitrogen and mean total phosphorus sorted by mean TSI (C).

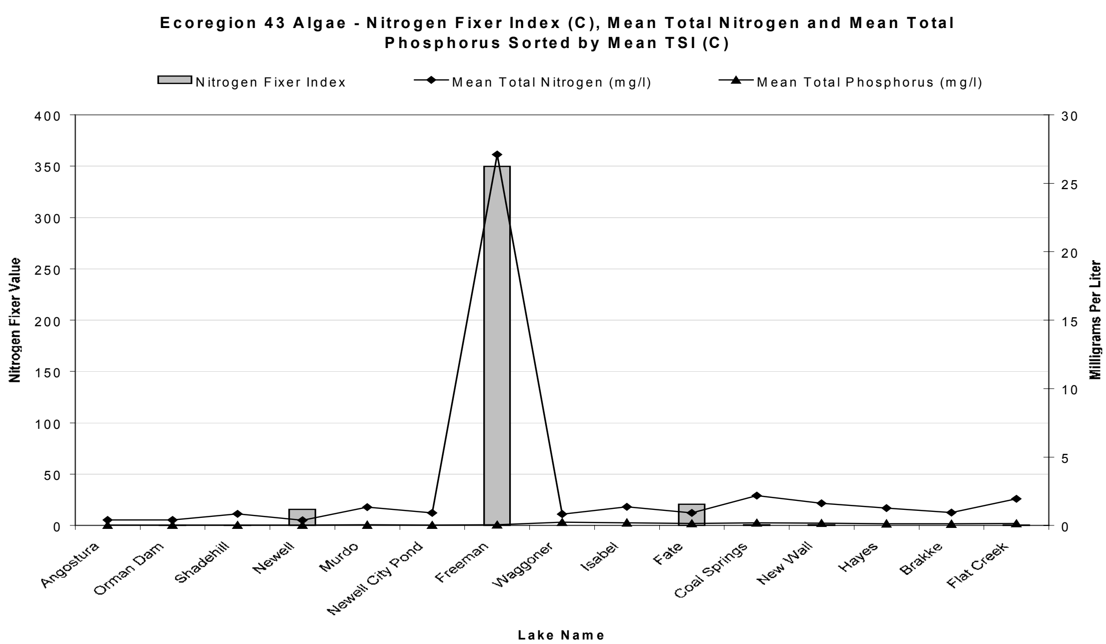

Figure 2.60. Ecoregion 43 Algae – Nitrogen fixer index (cells/ml), mean total nitrogen and mean total phosphorus sorted by mean TSI (C).

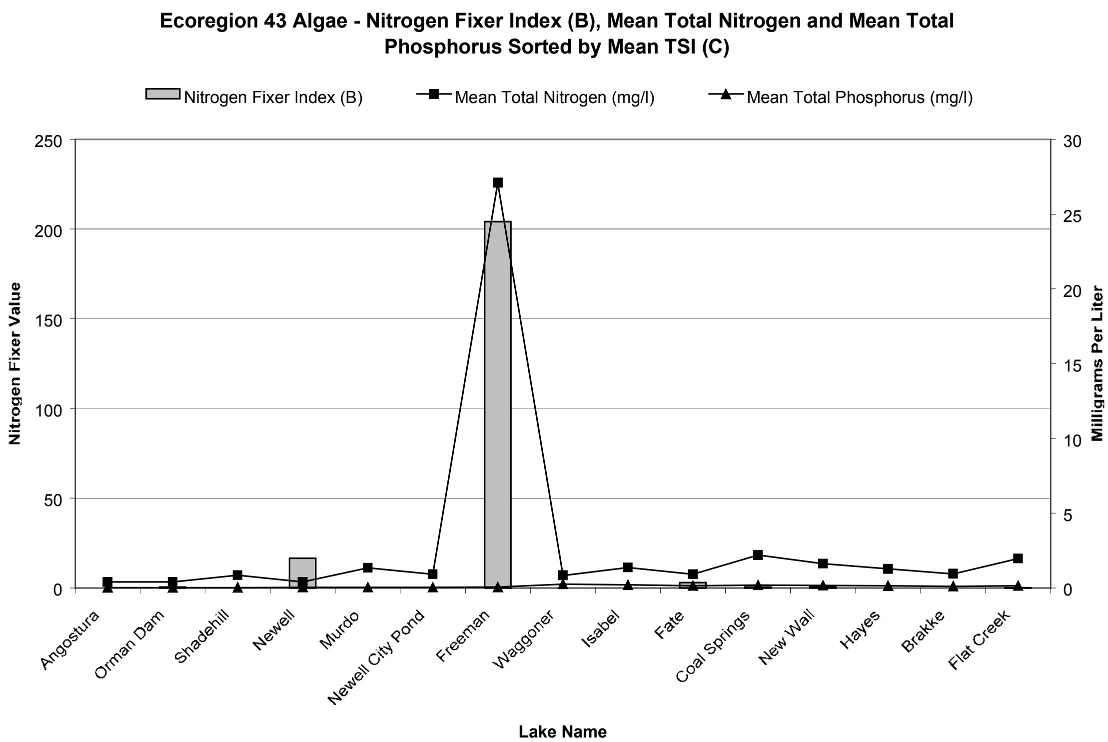

Figure 2.61. Ecoregion 43 Algae – Nitrogen fixer index (biovolume),mean total nitrogen and mean total phosphorus sorted by mean TSI (C).

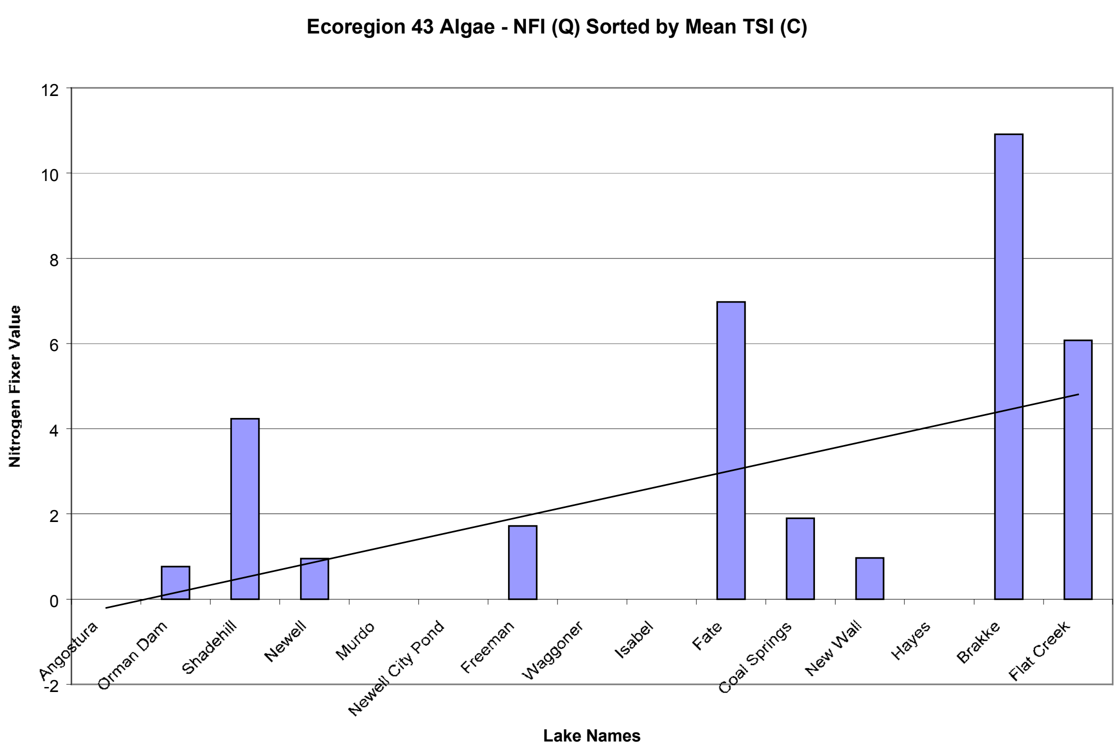

Figure 2.62. Ecoregion 43 Algae – Nitrogen fixer index (quotient), sorted by mean TSI (C).

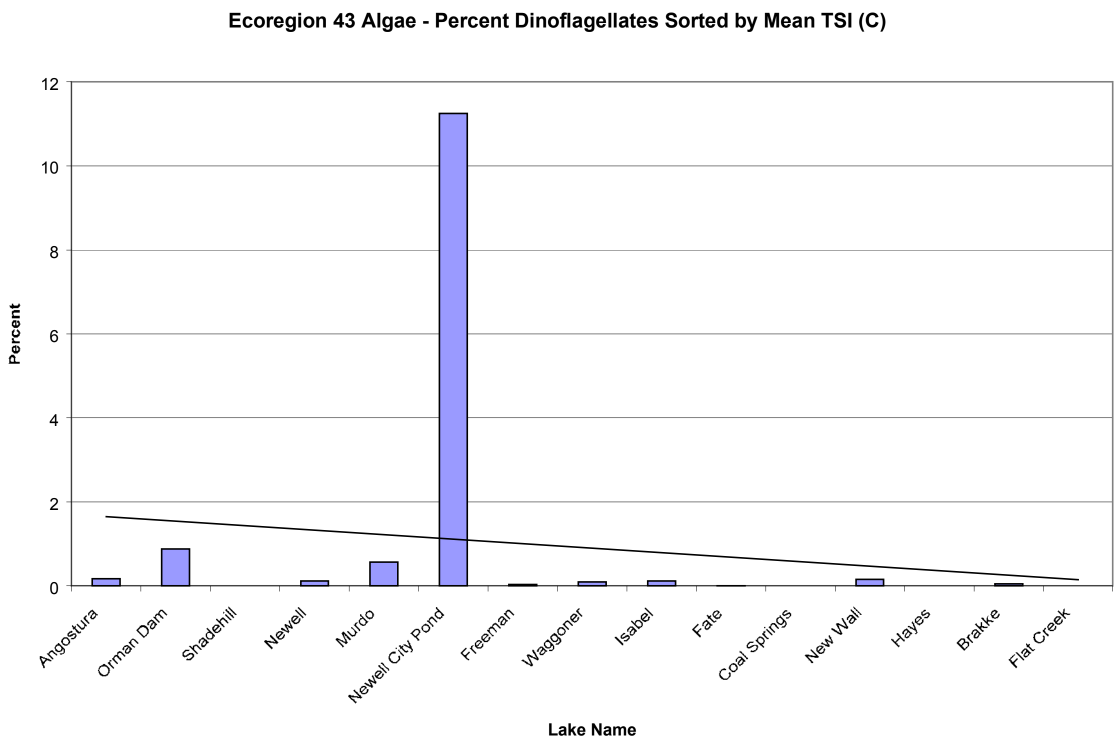

Figure 2.63. Ecoregion 43 Algae – Percent dinoflagellates sorted by mean TSI (C).

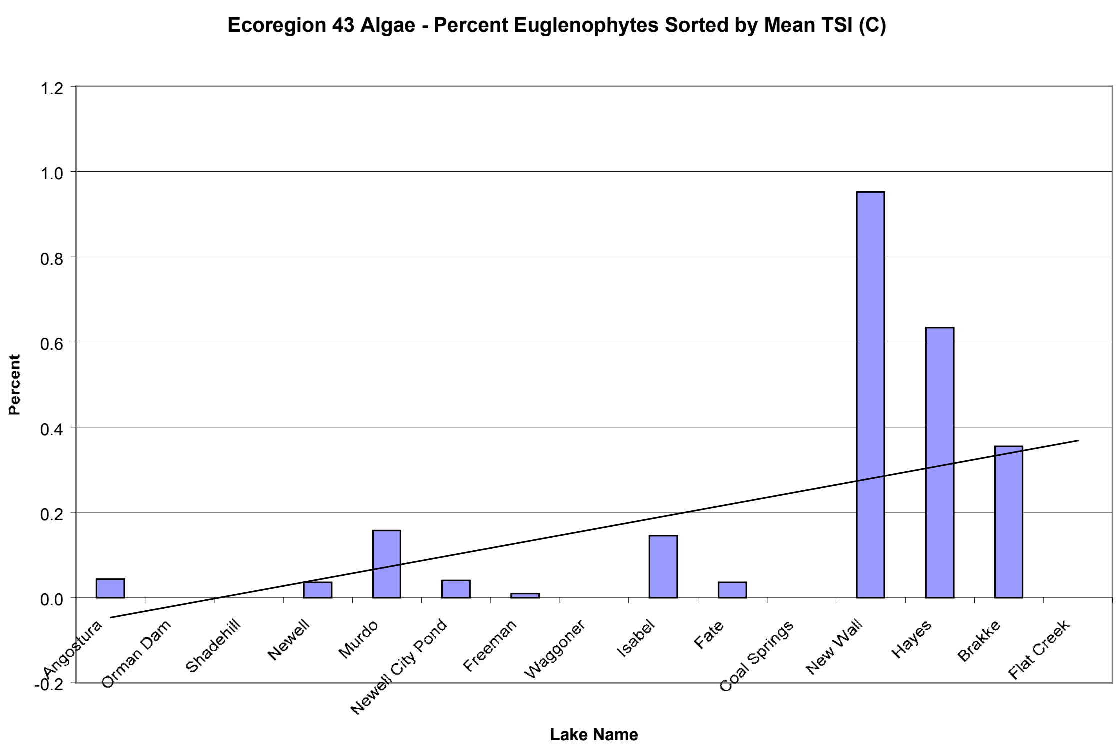

Figure 2.64. Ecoregion 43 Algae – Percent euglenophytes sorted by mean TSI (C).

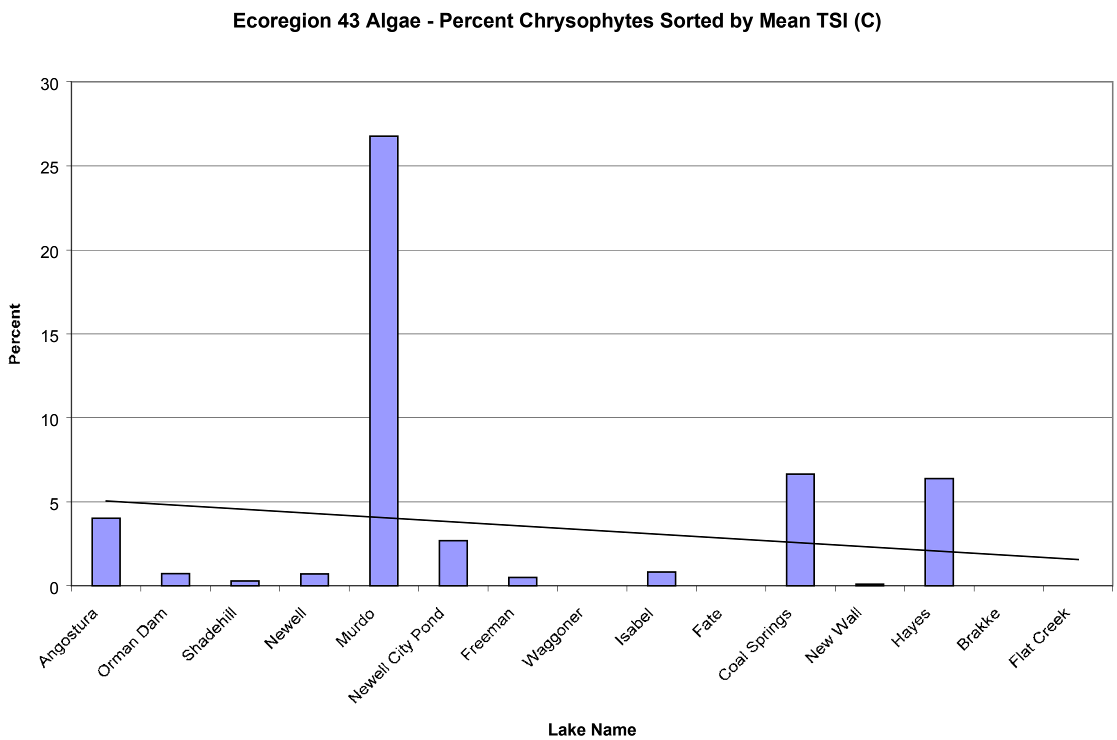

Figure 2.65. Ecoregion 43 Algae – Percent chrysophytes sorted by mean TSI (C).

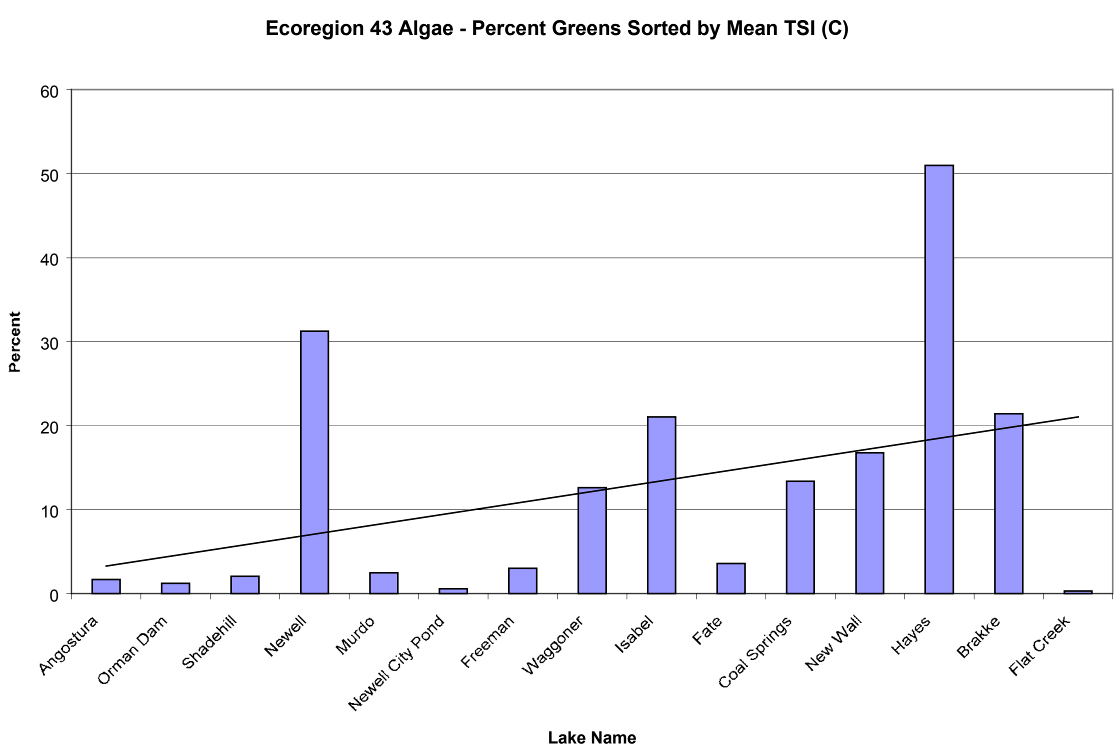

Figure 2.66. Ecoregion 43 Algae – Percent green algae sorted by mean TSI (C).

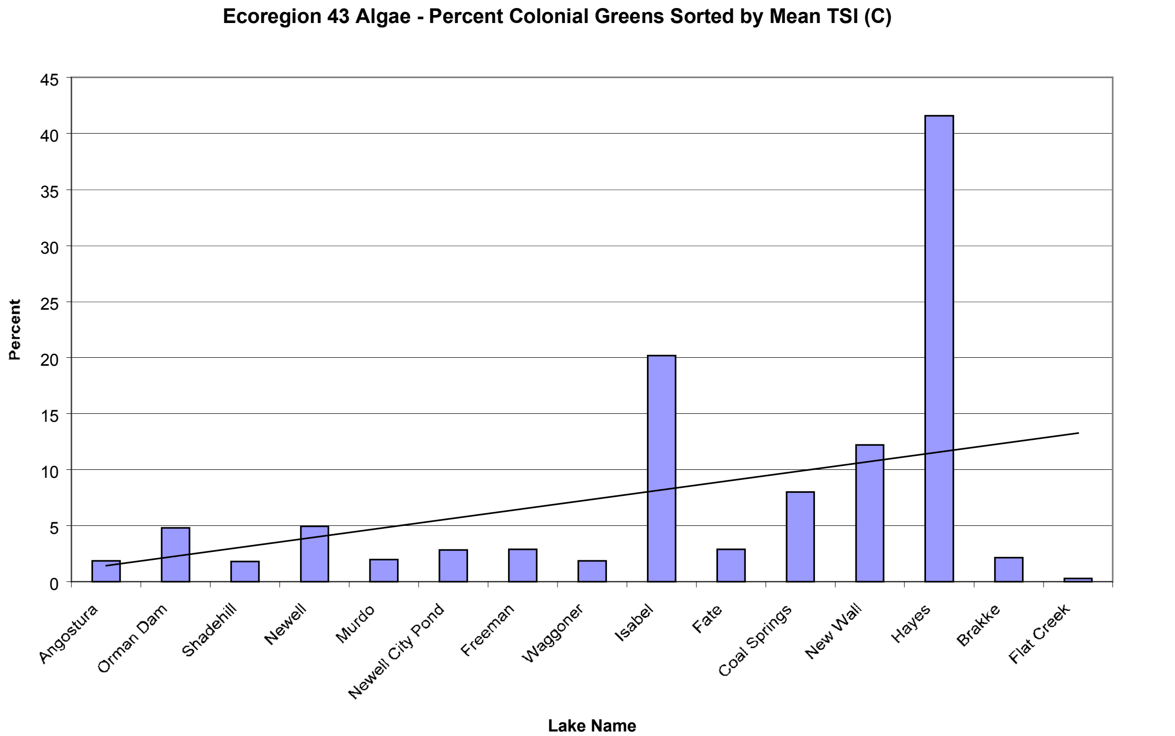

Figure 2.67. Ecoregion 43 Algae – Percent colonial green algae sorted by mean TSI (C).

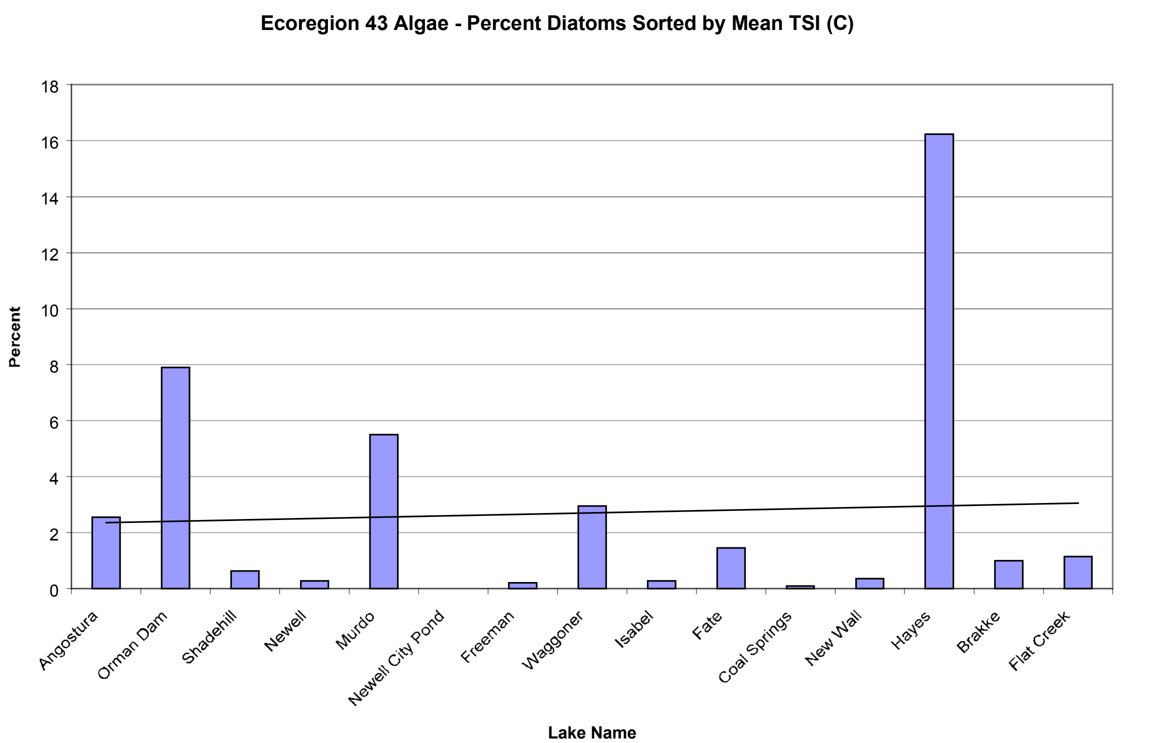

Figure 2.68. Ecoregion 43 Algae – Percent diatoms sorted by mean TSI (C).

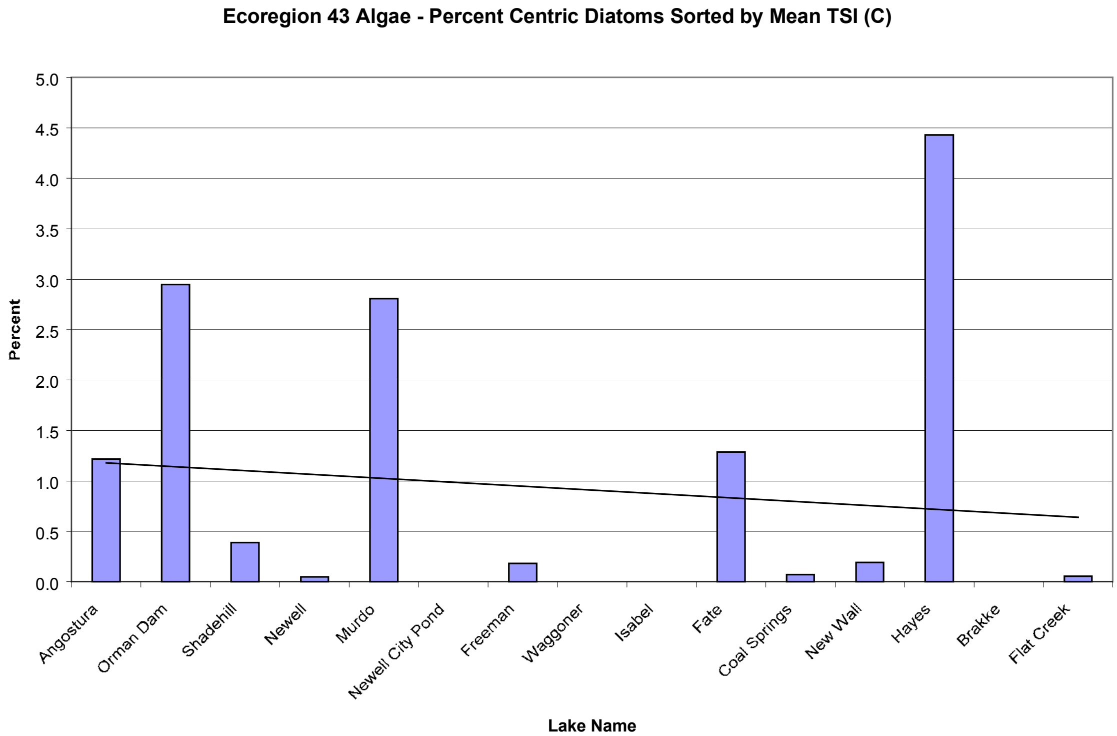

Figure 2.69. Ecoregion 43 Algae – Percent centric diatoms sorted by mean TSI (C).

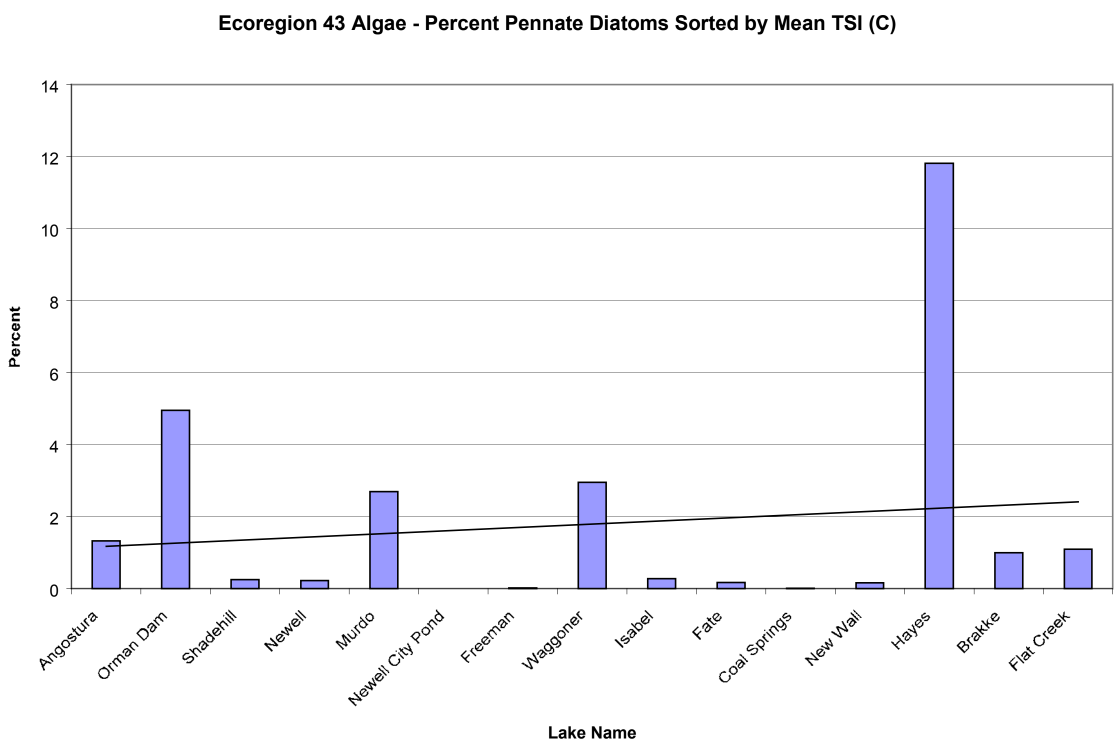

Figure 2.70. Ecoregion 43 Algae – Percent pennate diatoms sorted by mean TSI (C).

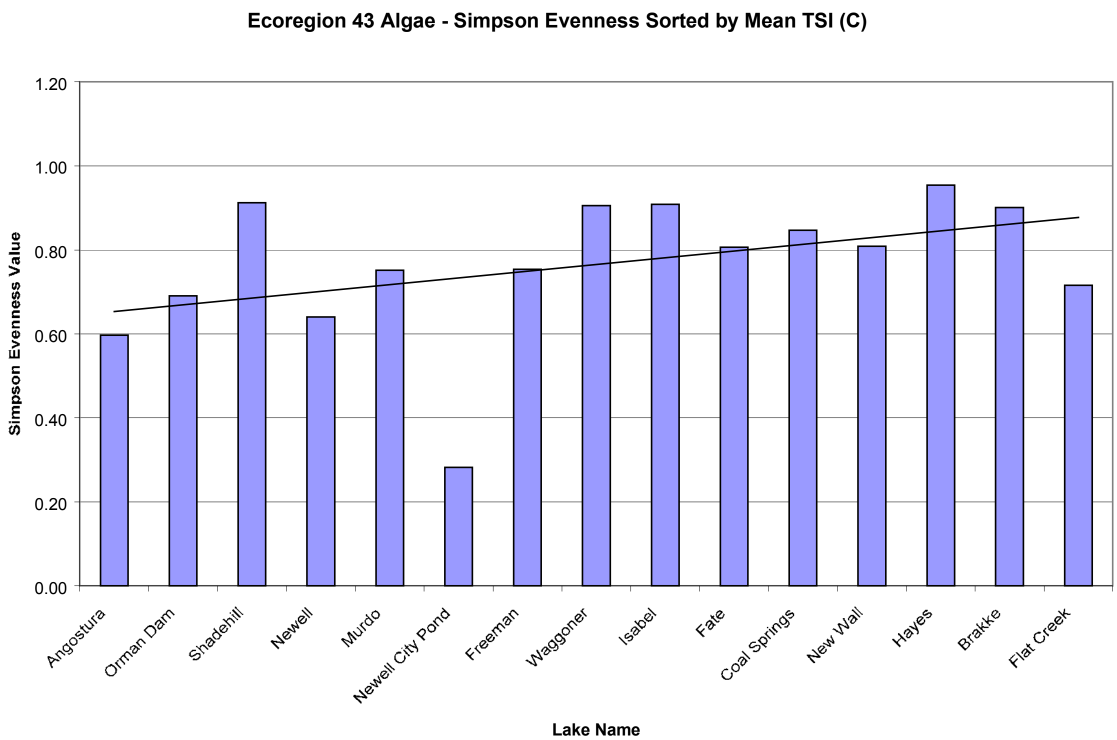

Figure 2.71. Ecoregion 43 Algae – Simpson evenness sorted by mean TSI (C).

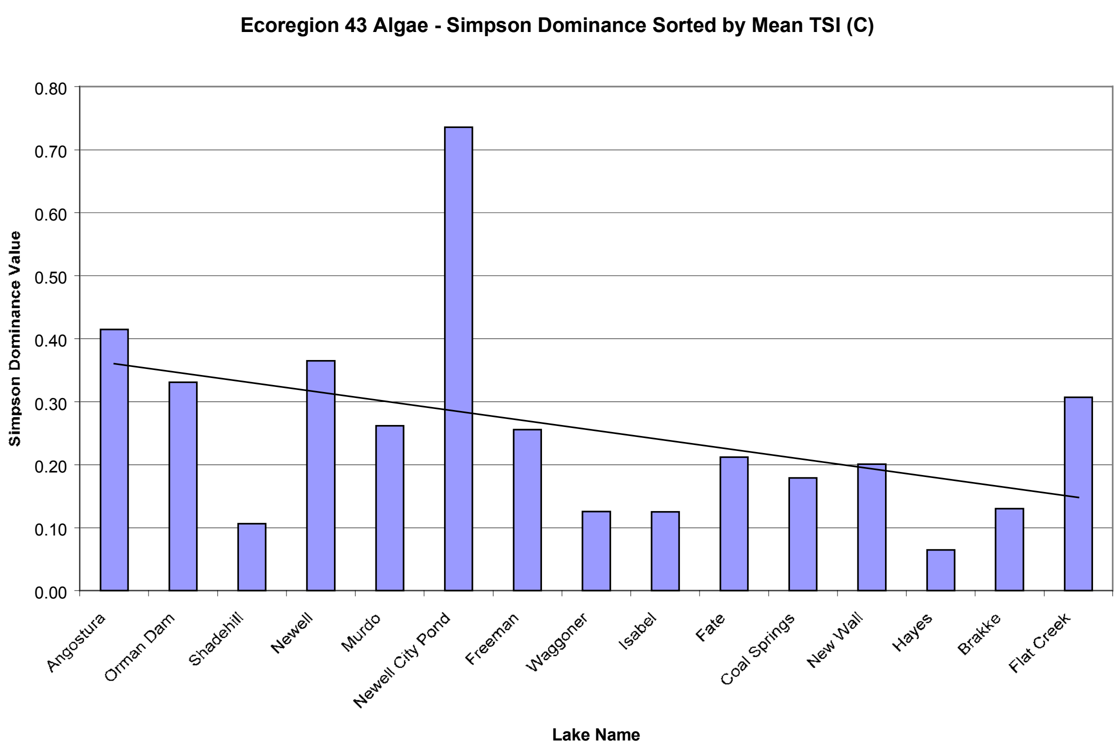

Figure 2.72. Ecoregion 43 Algae –Simpson dominance sorted by mean TSI (C).

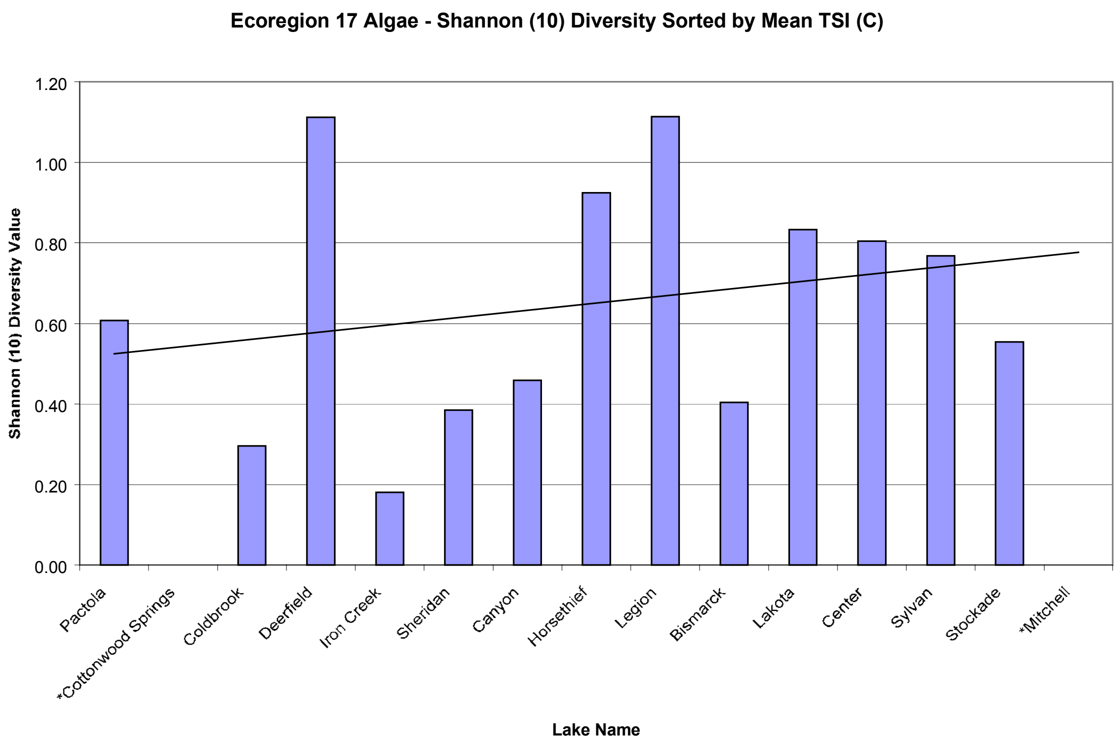

Figure 2.73. Ecoregion 17 Algae – Shannon (10) diversity sorted by mean TSI (C).

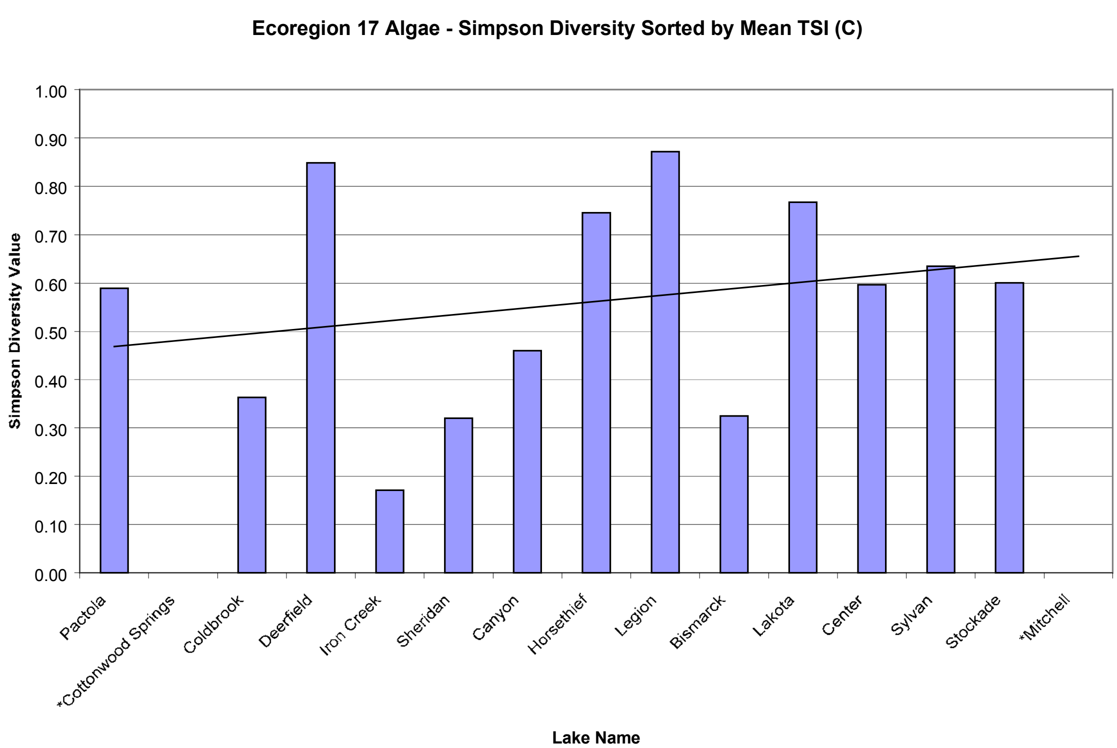

Figure 2.74. Ecoregion 17 Algae – Simpson diversity sorted by mean TSI (C).

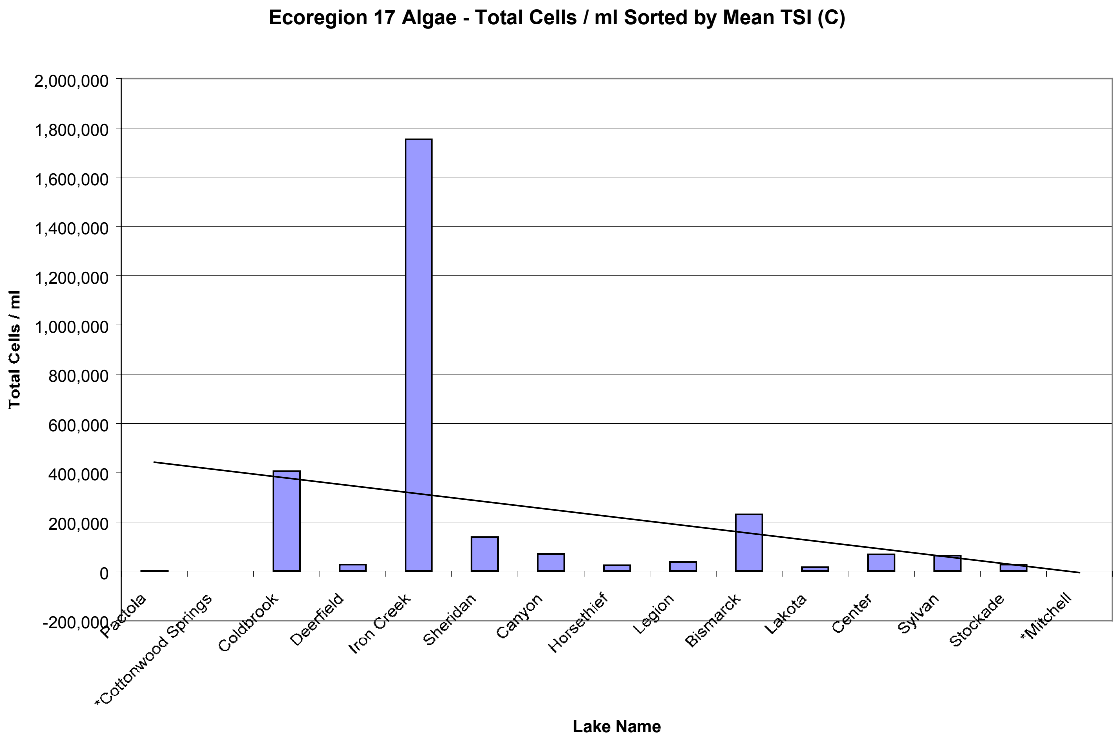

Figure 2.75. Ecoregion 17 Algae – Total cell/ml sorted by mean TSI (C).

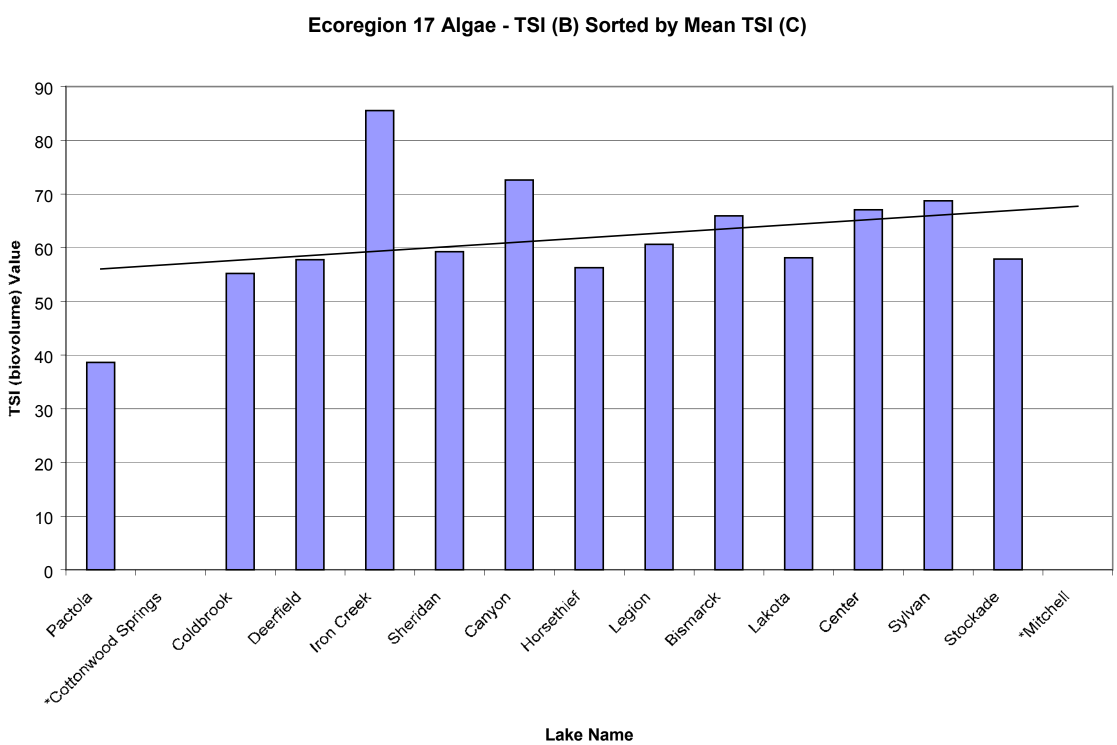

Figure 2.76. Ecoregion 17 Algae – TSI (biovolume) sorted by mean TSI (C).

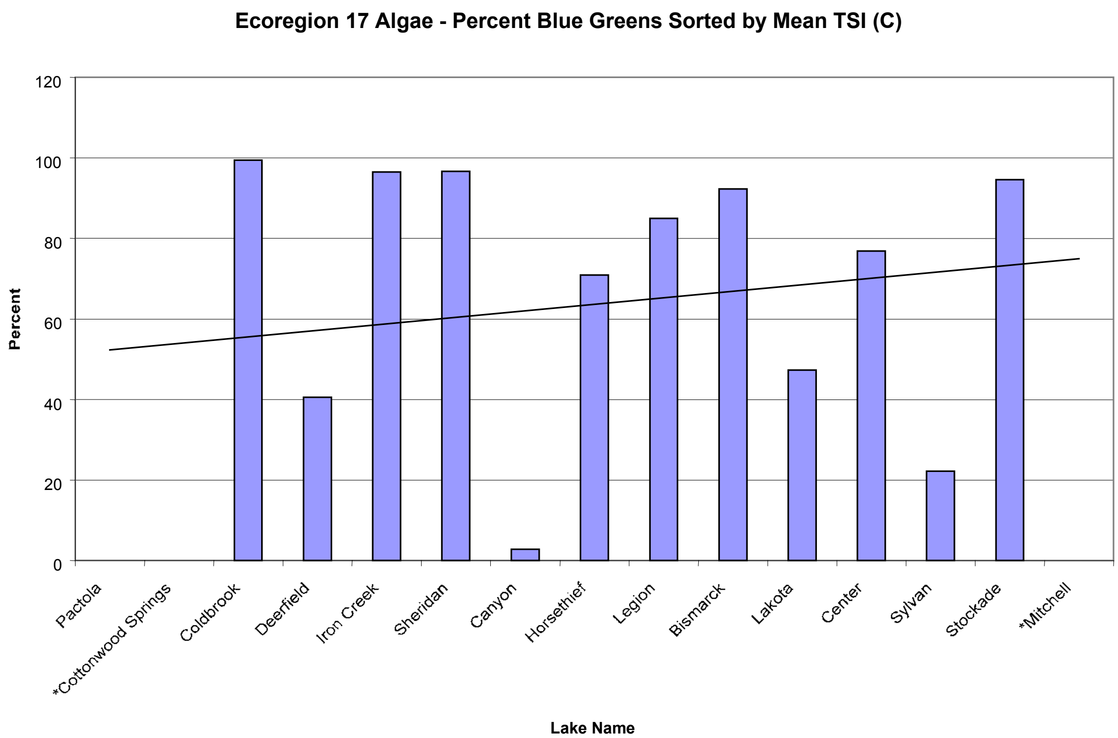

Figure 2.77. Ecoregion 17 Algae – Percent blue green algae sorted by mean TSI (C).

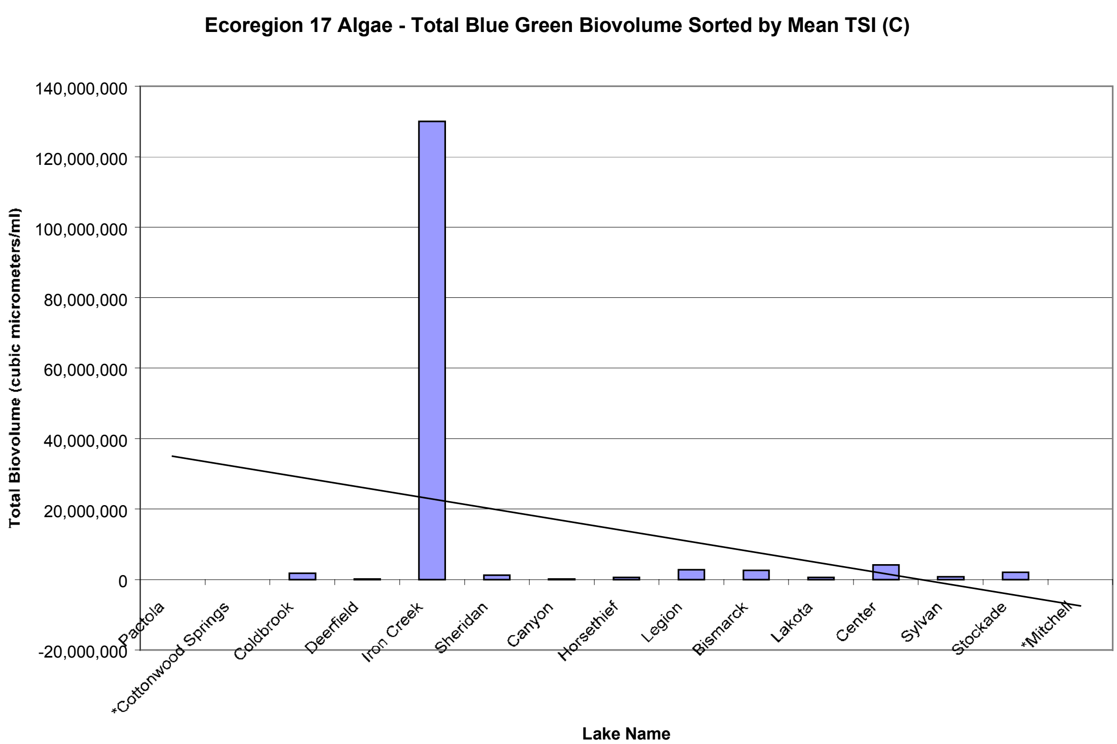

Figure 2.78. Ecoregion 17 Algae – Percent total blue green algae biovolume sorted by mean TSI (C)

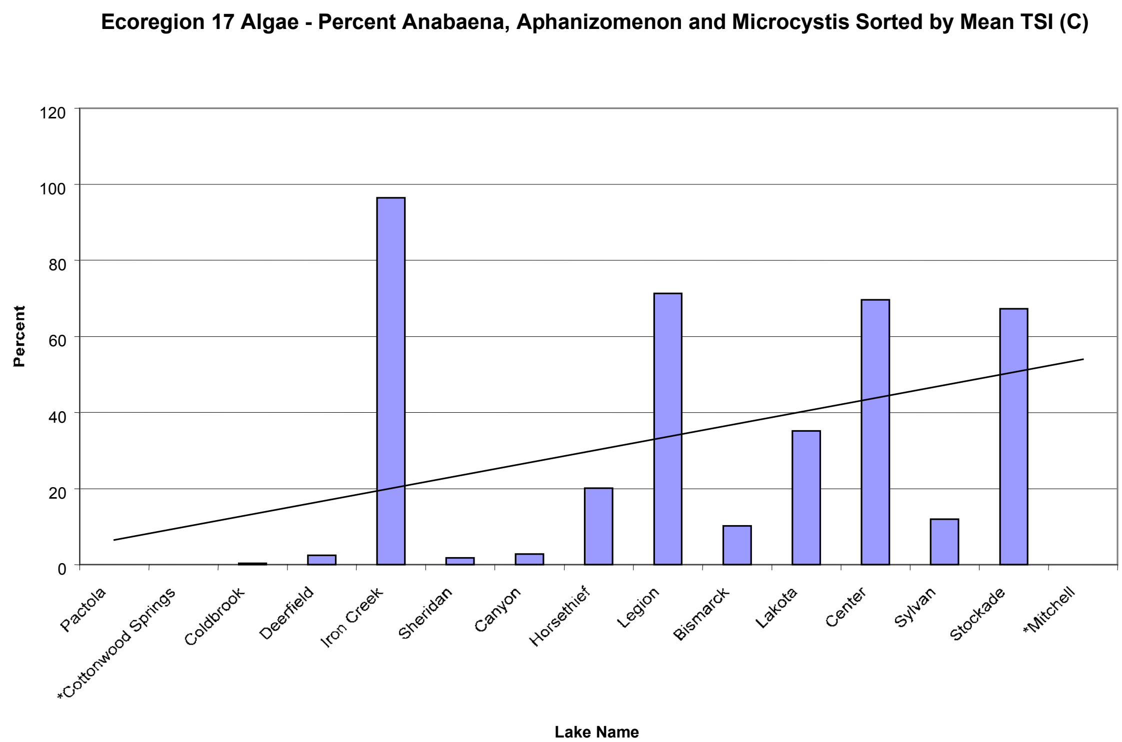

Figure 2.79. Ecoregion 17 Algae – Percent Anabaena, Aphanizomenon and Microcystis sorted by mean TSI (C).

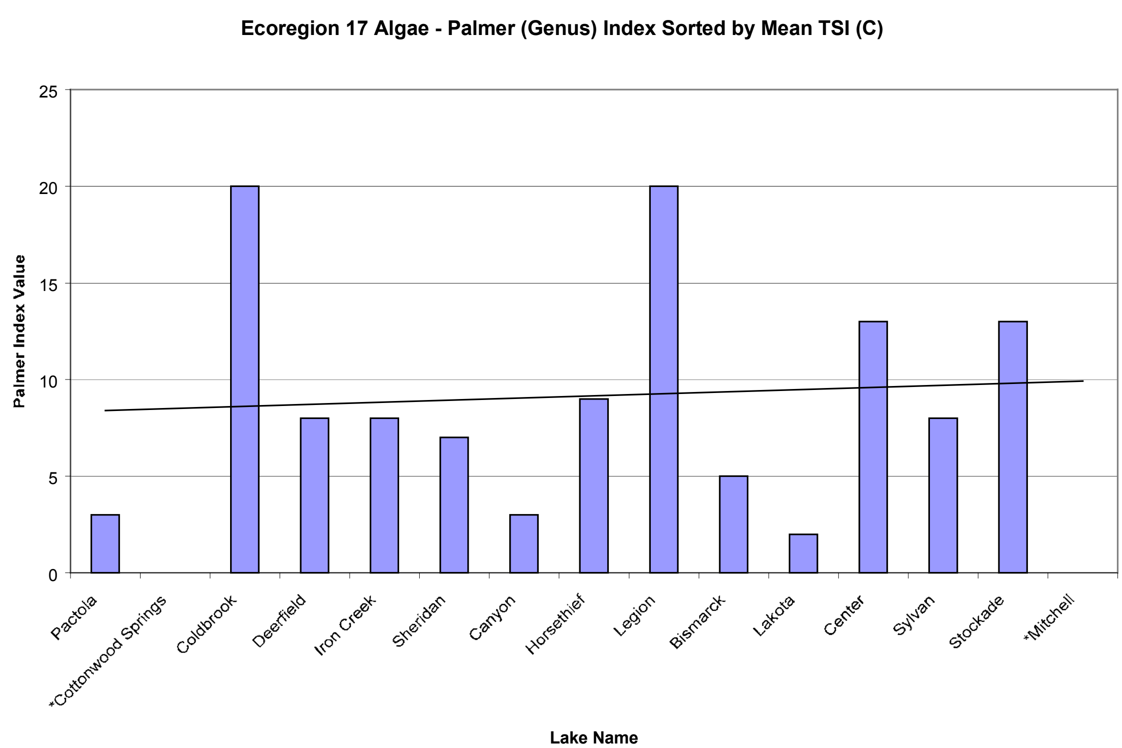

Figure 2.80. Ecoregion 17 Algae – Palmer index (Genus) sorted by mean TSI (C).

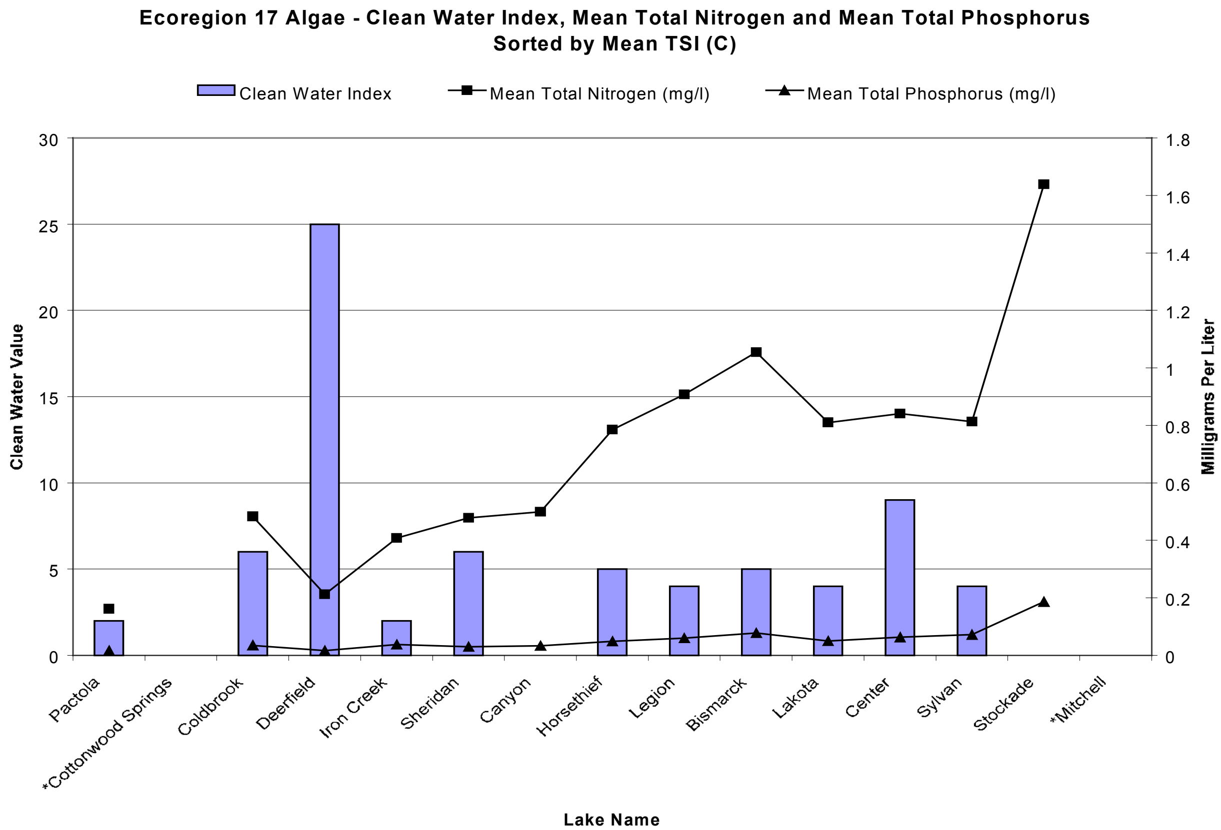

Figure 2.81. Ecoregion 17 Algae – Clean water index, mean total nitrogen and mean total phosphorus sorted by mean TSI (C).

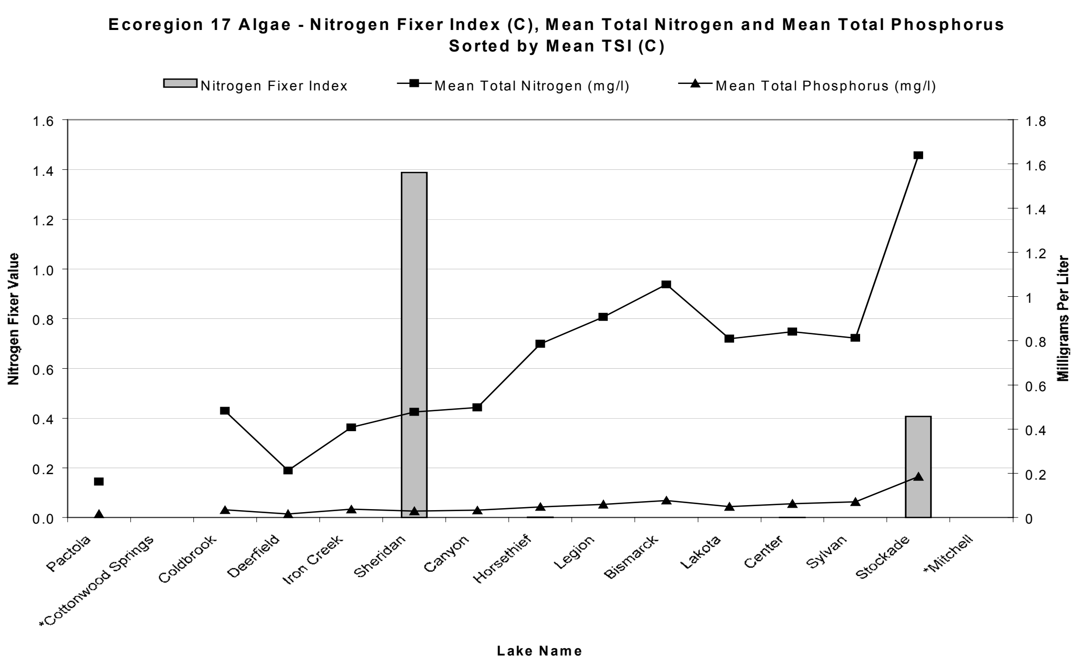

Figure 2.82. Ecoregion 17 Algae – Nitrogen fixer index (cells/ml),.mean total nitrogen and mean total phosphorus sorted by mean TSI (C).

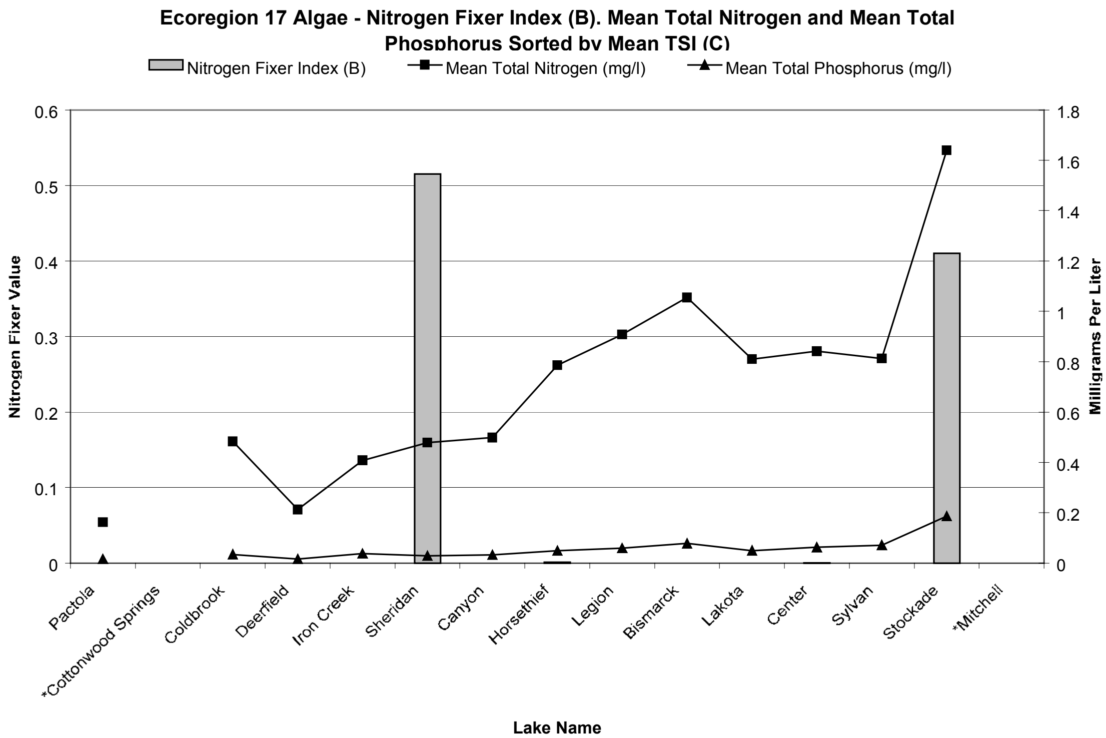

Figure 2.83. Ecoregion 17 Algae – Nitrogen fixer index (biovolume), mean total nitrogen and mean total phosphorus sorted by mean TSI (C).

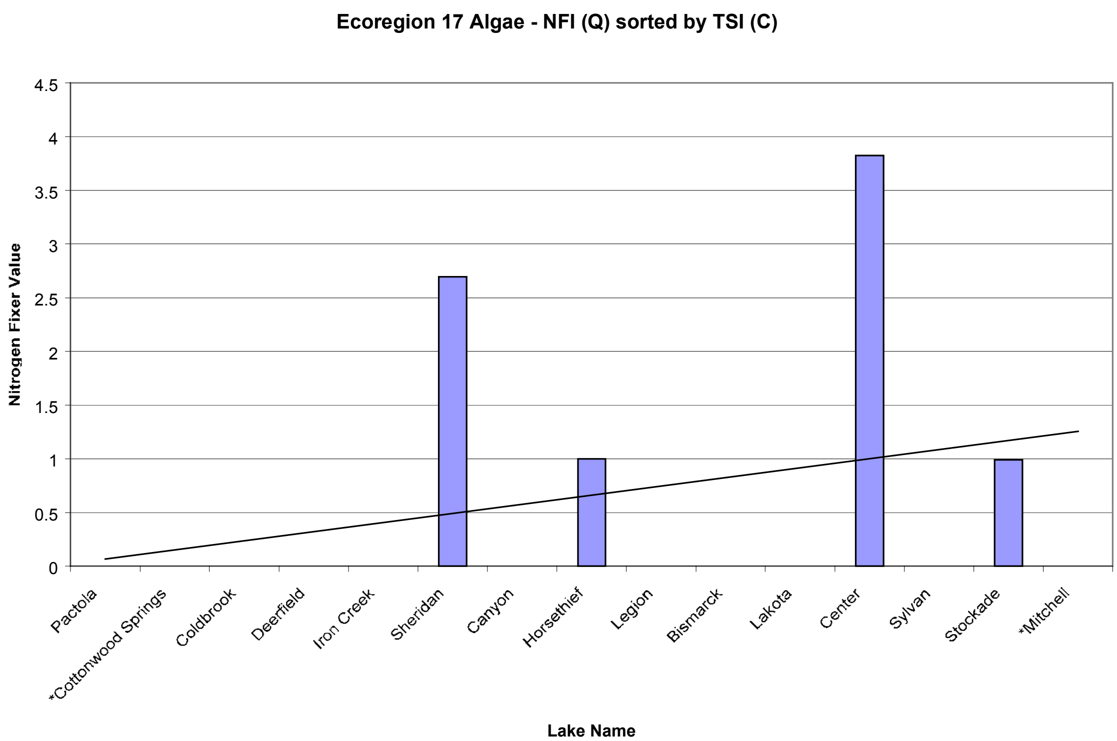

Figure 2.84. Ecoregion 17 Algae – Nitrogen fixer index (quotient), sorted by mean TSI (C).

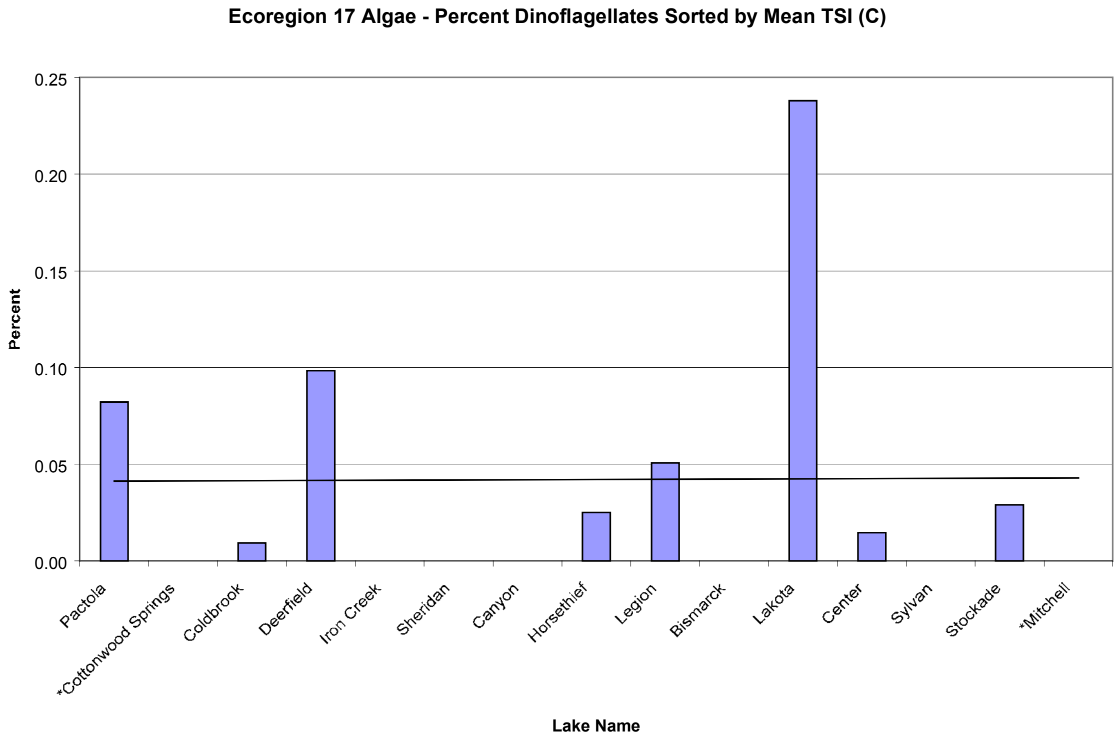

Figure 2.85. Ecoregion 17 Algae – Percent dinoflagellates sorted by mean TSI (C).

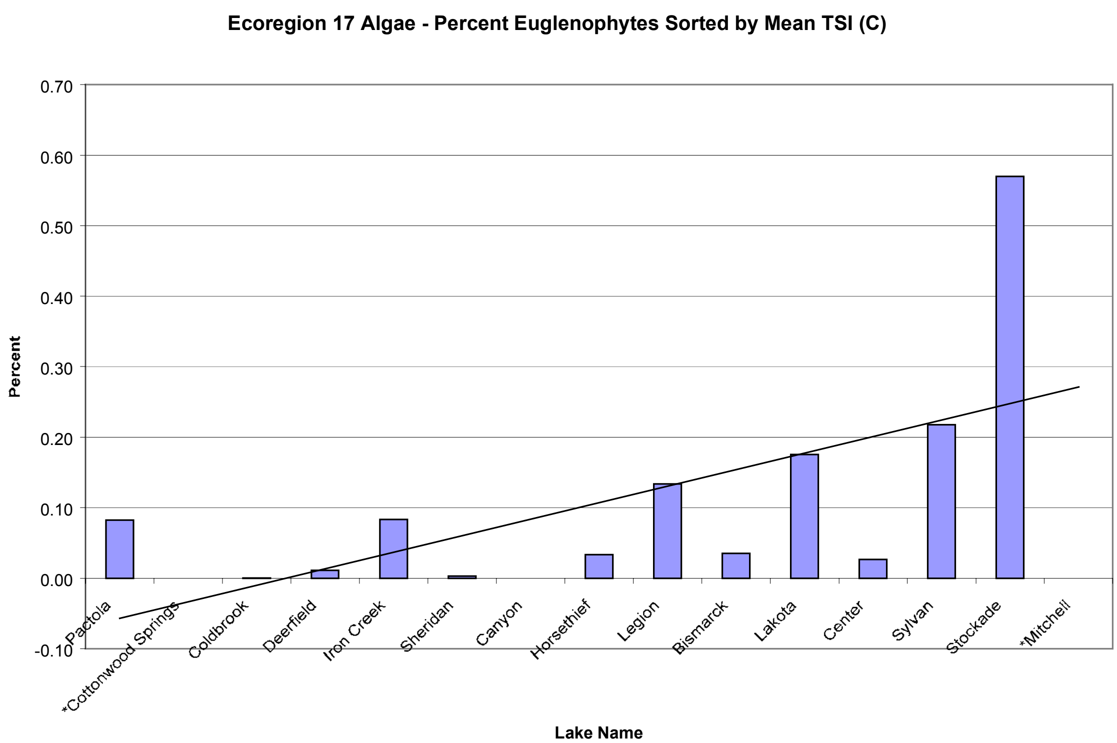

Figure 2.86. Ecoregion 17 Algae – Percent euglenophytes sorted by mean TSI (C).

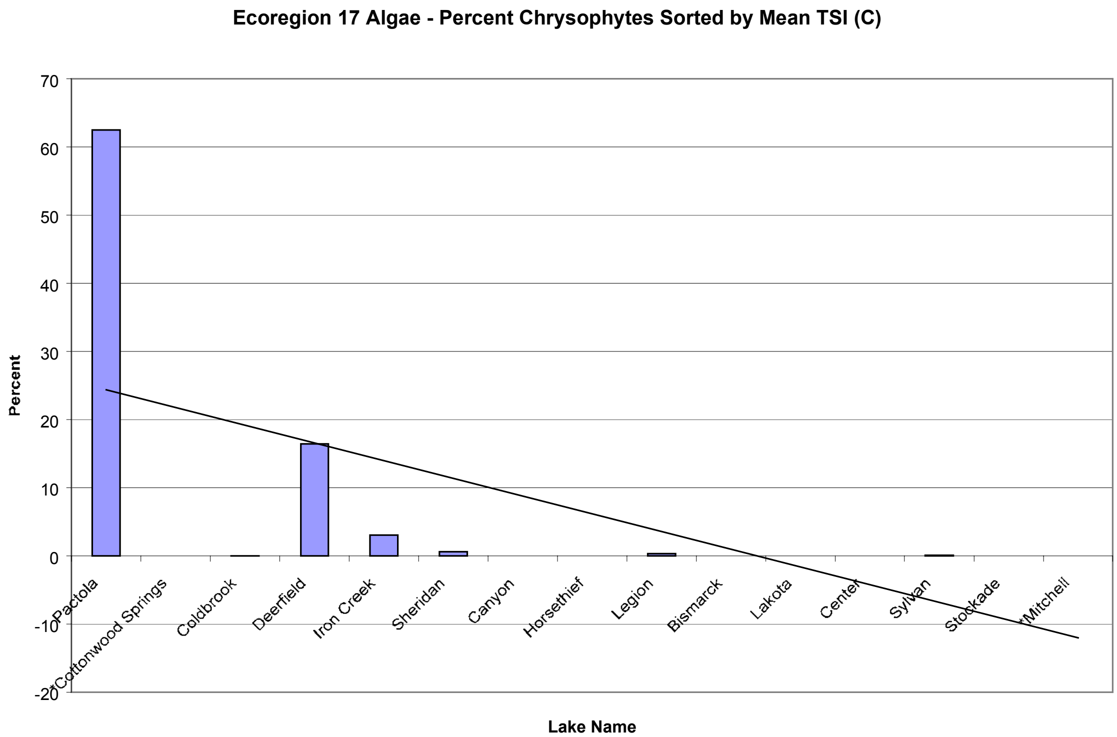

Figure 2.87. Ecoregion 17 Algae – Percent chrysophytes sorted by mean TSI (C).

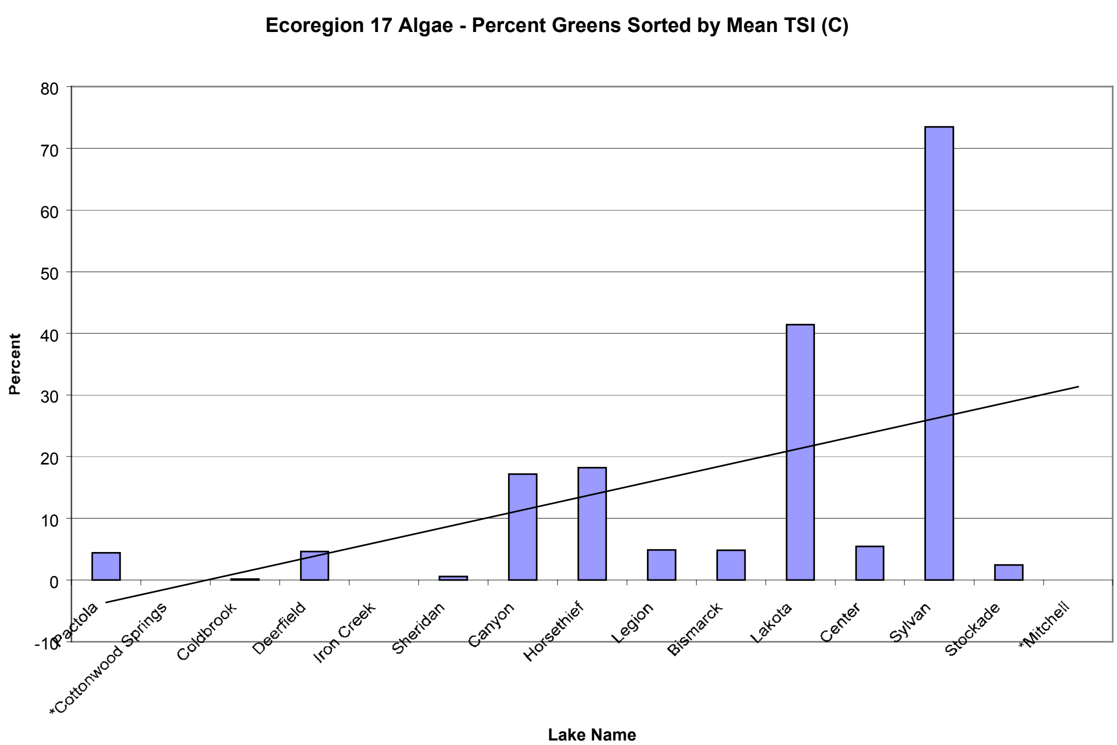

Figure 2.88. Ecoregion 17 Algae – Percent green algae sorted by mean TSI (C).

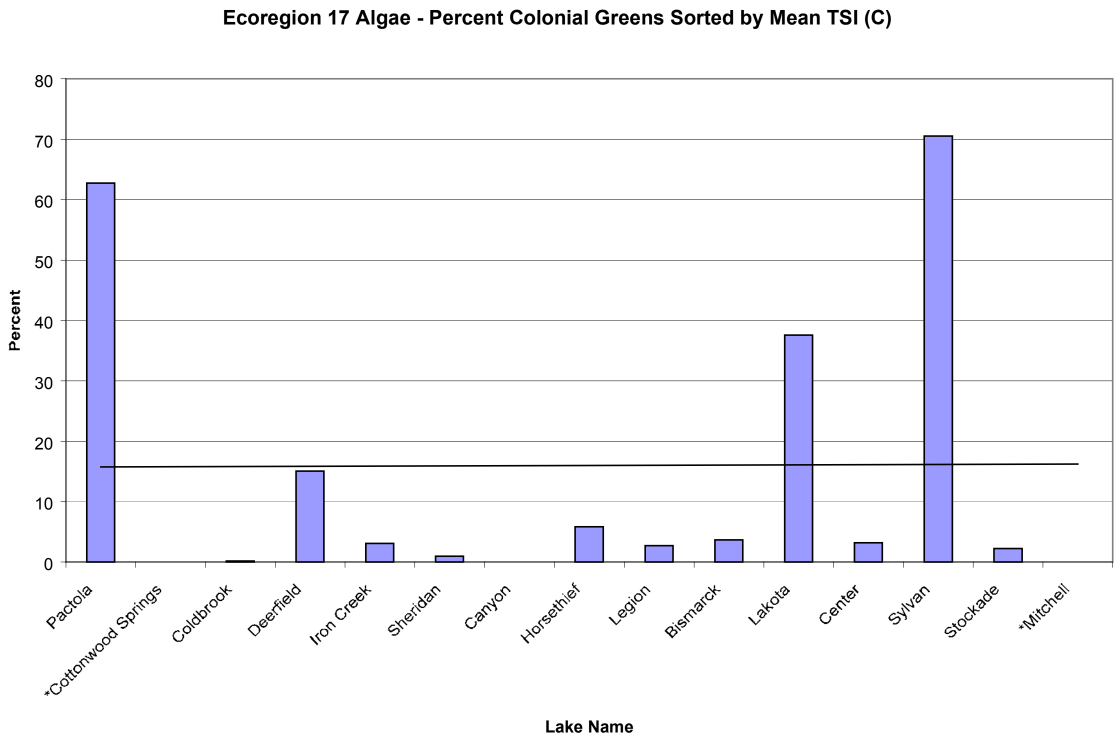

Figure 2.89. Ecoregion 17 Algae – Percent colonial green algae sorted by mean TSI (C).

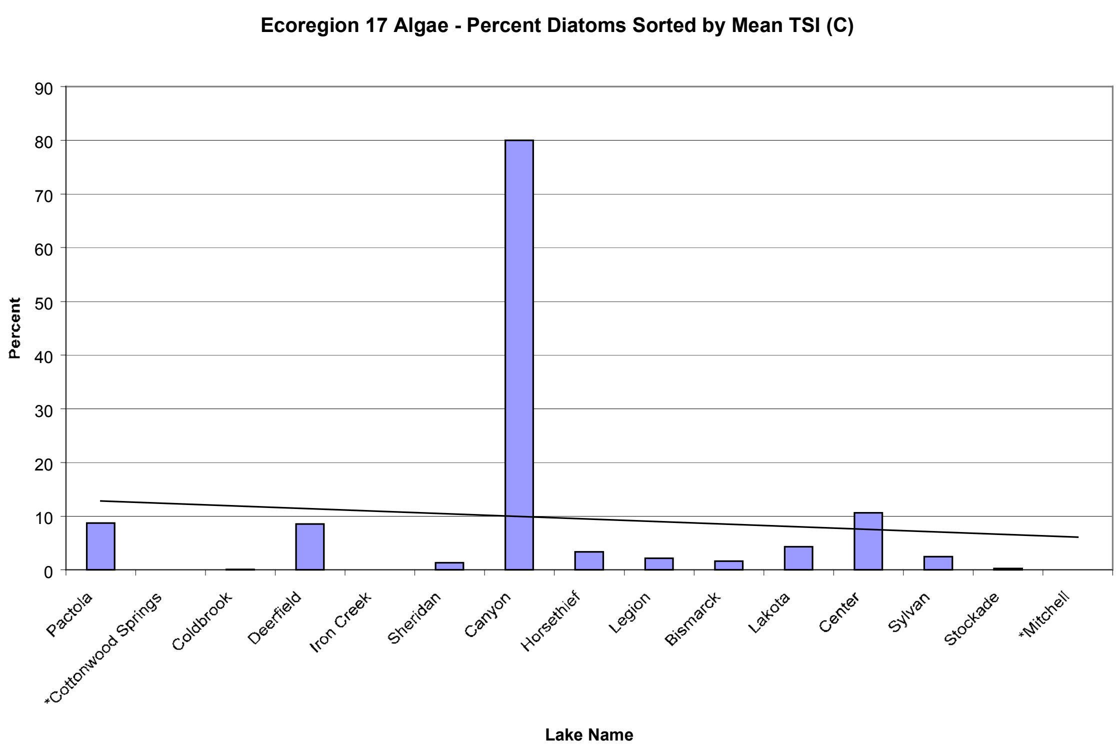

Figure 2.90. Ecoregion 17 Algae – Percent diatoms sorted by mean TSI (C).

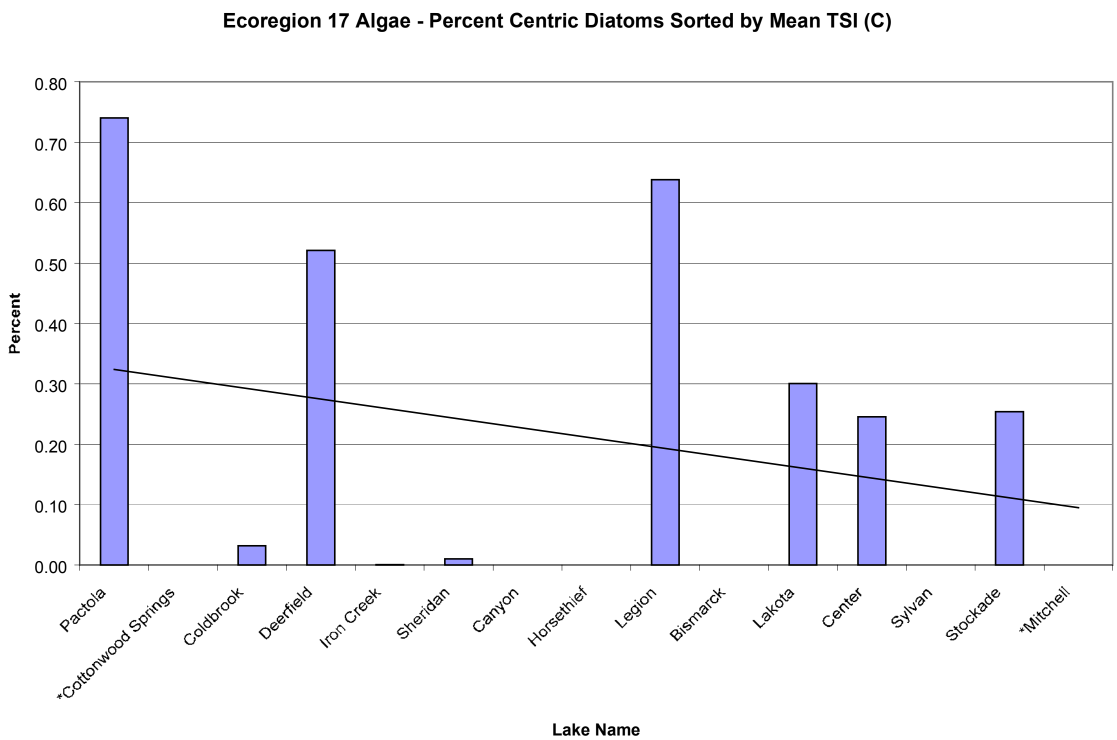

Figure 2.91. Ecoregion 17 Algae – Percent centric diatoms sorted by mean TSI (C).

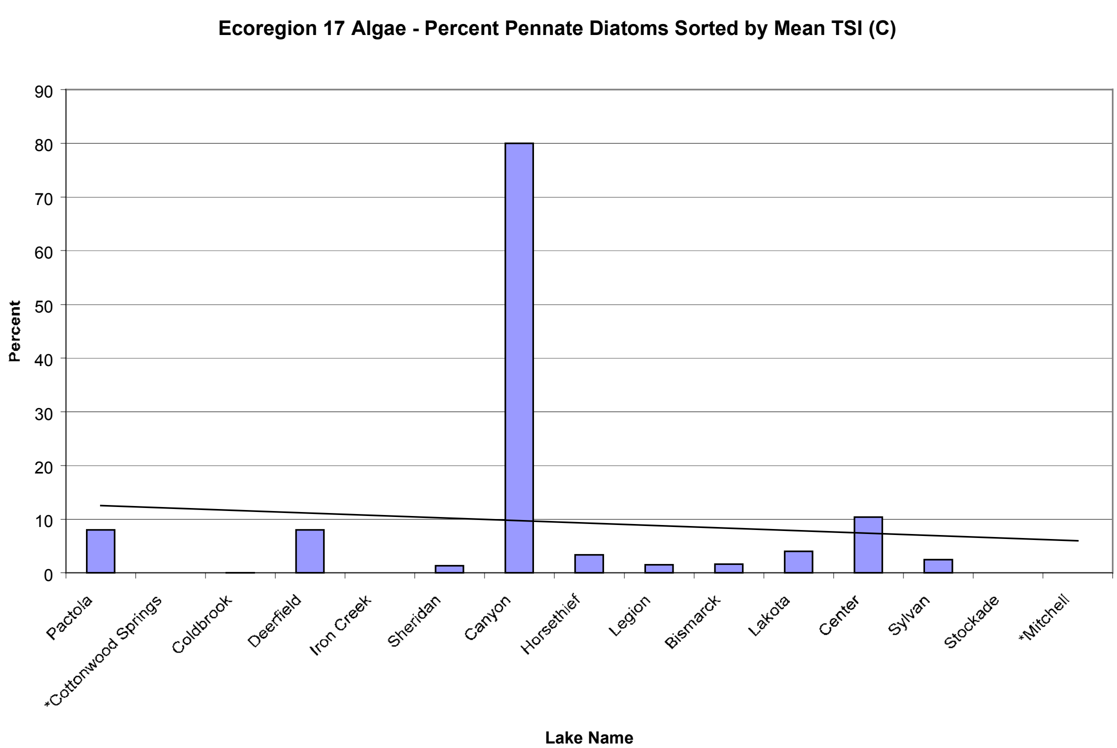

Figure 2.92. Ecoregion 17 Algae – Percent pennate diatoms sorted by mean TSI (C).

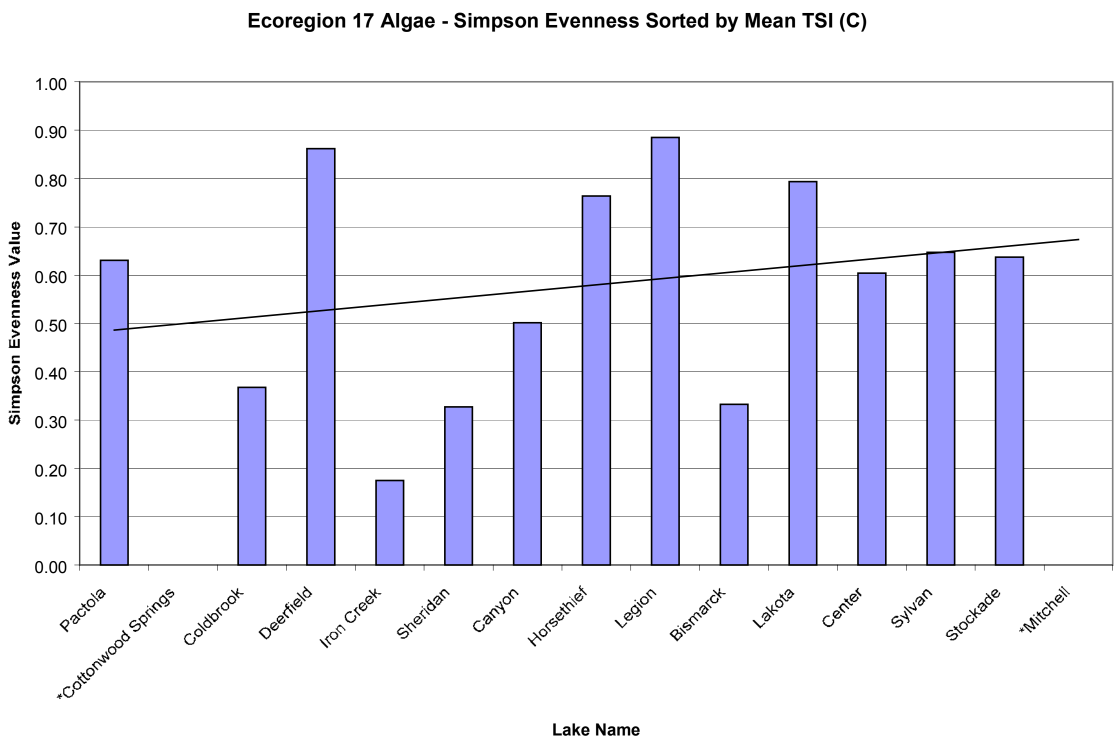

Figure 2.93. Ecoregion 17 Algae – Simpson evenness sorted by mean TSI (C).

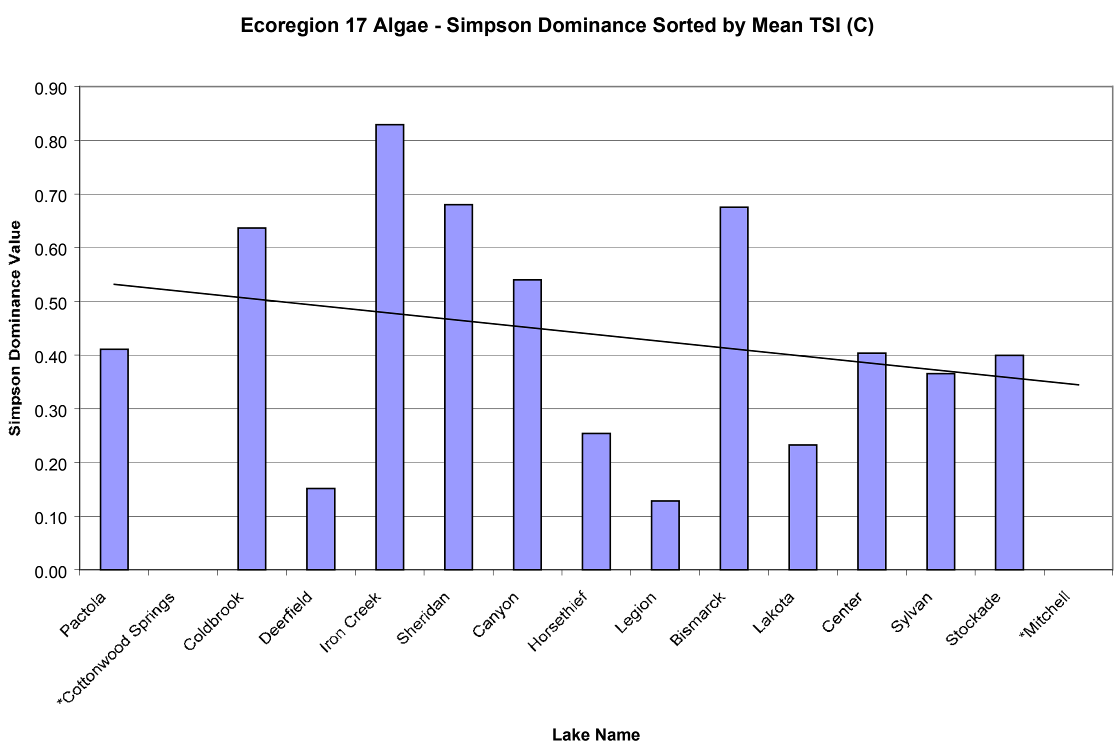

Figure 2.94. Ecoregion 17 Algae –Simpson dominance sorted by mean TSI (C).

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